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STRAW UTILIZATION BY BEEF CATTLE

by

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ABSTRACT

A study was conducted in 1974-75 to determine the influences of diets containing high levels of barley straw on the performance of beef cattle.

Maintenance diets containing 86% ground, pelleted or chopped straw and 5.7, 6.9 or 9.9% crude protein (moisture-free basis) were evaluated with 36 individually fed cows. The cows receiving pelleted diets tended ($P < 0.10$) to consume more feed daily, had a higher ($P < 0.05$) digestible energy intake and gained more ($P < 0.01$) weight during an 84 day feeding period than the other groups. No significant differences were observed in feed or energy intake for the cows fed at the different dietary protein levels. The weight gain during the feeding period increased ($P < 0.01$) as dietary protein level increased. However, no differences due to treatments were observed for weight loss to post-calving or for calf birth weights.

Twenty-four cows were individually fed 86% straw-based diets, supplemented with either soybean meal or barley based N-glucosyl ureide, containing 5.7, 6.9 or 9.9% crude protein (moisture-free basis). No significant differences due to dietary protein source or level were observed for feed or energy consumption, cow weight changes or calf birth weights.

Three diets containing 78, 86 or 94% straw, but

similar levels of crude protein, were individually fed to 12 cows. Digestible energy intake decreased ($P < 0.05$) when the straw level of the diet increased. This resulted in decreased ($P < 0.01$) weight gains during a 105 day feeding period as dietary straw level increased. Weight losses from the start of the trial to post-calving were the largest for the group fed the high straw diet ($P < 0.05$). Calf birth weights were not affected by the treatments.

The final comparison in the maintenance study involved eight cows which were individually fed straw-based diets supplemented with 14% concentrate or 22% clover-brome hay. The concentrate supplemented group consumed more feed and protein ($P < 0.05$), gained more weight ($P < 0.05$) in the feeding period, lost less weight to post-calving ($P < 0.05$) and had a lower level of plasma free fatty acids ($P < 0.01$) than the hay supplemented group. No differences in calf birth weights were observed.

The performance of 18 beef steers individually fed diets containing 40, 55 or 70% barley straw in isonitrogenous pelleted diets was examined in another experiment in this study. As the level of straw in the diet increased, there was a trend ($P < 0.10$) toward decreased average daily gains, and more feed ($P < 0.05$) but less concentrate was required per unit of gain. There was no difference among treatments in the amount of digestible energy required per unit of gain. Carcass weights decreased ($P < 0.01$) as did fat cover ($P < 0.05$) as dietary straw level increased.

The effects of weathering on barley straw were studied in the final experiment. Normal outdoor weathering appeared to decrease the cellular contents of the straw. Reduced voluntary straw intake ($P < 0.05$) and apparent digestibilities ($P < 0.01$) of dry matter, gross energy and nitrogen were obtained with sheep when rations containing weathered straw were compared with those containing fresh straw.

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TABLE OF CONTENTS

LIST OF TABLES

Table	Description	Page

Table	Description	Page

1. INTRODUCTION

The production of cereal grains has long been recognized as a major segment of the agricultural industry of Western Canada. Straw has been regarded mainly as a by-product of grain production, although the weight of straw produced consistently exceeds that of grain for barley (Beaven, 1947), oats (Findlay, 1956) and wheat (Dubetz and Bole, 1973; Mack, 1973).

As world population continues to expand, there will be an increasing demand for cereal grains. The impact on the beef cattle industry would be expected to be two-fold. Firstly, cereal grains will be available as a feedstuff for cattle only at increased prices, and secondly, increased cereal grain production to meet increased demand will result in larger quantities of the by-product, straw.

Straw has been used as a feedstuff for cattle since the early days. It is now being used by a greater number of producers in Western Canada, although there are few detailed studies in which straw has been used as a major constituent of the diet.

The purpose of these studies was to evaluate the use of high levels of barley straw in winter maintenance diets for dry pregnant beef cows and in production diets for growing and finishing beef steers. The nutritive value of straw which had been subjected to outdoor weather conditions for one year was also evaluated.

2. REVIEW OF LITERATURE

2.1. COMPOSITION AND ENZYMATIC DEGRADATION OF STRAW

To understand the problems of utilization of straw by ruminants it is necessary to review the composition of straw. In this regard, Van Soest (1967) has divided the organic constituents of forages into two fractions (cellular contents and cell walls) using a neutral detergent solution. Analyses have shown that the dry matter of straw consists of approximately 18 to 30% cellular contents, with the remainder being cell walls (Moore, 1966).

2.1.1. Cellular Contents

The cellular contents include sugars, soluble carbohydrates, starches, pectins, nonprotein nitrogen compounds, proteins, lipids and other solubles, all of which are completely or almost completely nutritionally available to ruminants (Van Soest, 1967).

2.1.2. Cell Walls

Van Soest (1969) considers cell walls to consist of hemicellulose and cellulose, which are partially available to digestion in ruminants, and heat-damaged protein and lignin which are indigestible. Heat-damaged protein does not occur naturally. The proportion of cell walls in the plant increases with maturity, thus the digestibility of organic matter decreases with maturity. The compostion of the cell wall fraction is also important. Ololade et al (1970) examined

the composition of the cell wall fraction of barley straw and demonstrated that there was slightly more cellulose than hemicellulose in his samples, and that 12% of this fraction was lignin.

2.1.2.1. Cellulose

More than 50% of the total organic carbon in the biosphere is in the form of cellulose, a major constituent of the plant cell wall (Lehninger, 1970). It is composed of D-glucose units in which the linkage between units is $\beta(1 \rightarrow 4)$. Ruminants have a dense population of bacteria and protozoa in the rumen which produce cellulases that have the capability of hydrolyzing cellulose to β-D-glucose (Lehninger, 1970). In an aqueous solution β-D-glucose forms an equilibrium mixture with α-D-glucose, which is the normal anomeric form of glucose metabolized by animals (White et al, 1964). Most of the hydrolysis of cellulose occurs in the rumen, however Church (1971) cites work showing that as much as 20% of cellulose digestion can occur post-ruminally.

2.1.2.2. Hemicellulose

In plant cell walls, densely packed cellulose fibrils surround the cell in a regular, near crystalline arrangement. These fibrils are cemented together by a matrix of three other polymeric materials (pectins, extensins and hemicellulose) (Lehninger, 1970). Pectins and extensins are present in minor amounts and were included as cellular contents by Van Soest (1967) since they are highly digestible.

Hemicelluloses from grasses contain a main chain of xylan made up of $\beta(1 \rightarrow 4)$ xylose units with side chains containing methylglucuronic acid (White et al, 1964).

Micro-organisms in the rumen produce enzymes capable of hydrolyzing hemicellulose to monomeric units. Most micro-organisms involved in this process are the same as those which break down cellulose (Hungate, 1966). Little information is available concerning the mechanisms of these reactions, however Walker and Hopgood (1961) have isolated an enzyme from sheep microflora which is capable of catalyzing the hydrolysis of hemicellulose. Almost no digestion of hemicellulose occurs post-ruminally in the digestive tract of sheep (Bailey and MacRae, 1970). The availability of hemicellulose tends to be lower than that of cellulose as lignification increases (Keys et al, 1969; Van Soest, 1969).

2.1.2.3. Lignin

Lignin is the final major constituent of cell walls in plants. It consists mainly of phenylpropane units joined together by ethereal linkages and carbon-to-carbon bonds (Schubert, 1965). Animals do not produce enzymes capable of degrading lignin. All organisms which have been isolated that are capable of degrading lignin are aerobic and most are fungi (Schubert, 1965). There is thus little or no digestion of lignin in the ruminant.

Cross-linkages are thought to occur between lignin and other constituents forming a lignocellulose complex. Lignin thus not only acts as an inert diluent in feedstuffs,

but because of its close physical and chemical association with the cell wall polysaccharides, it frequently acts as an encrusting barrier which impedes the microbiological breakdown of cellulose and hemicellulose (Pigden and Heaney, 1969).

The lignin content of forages increases from about 2% in immature forages to 20% in mature forages (Mowat et al, 1969; Pigden and Heaney, 1969). The proportion of the plant occurring as stems relative to leaves also increases as plants approach maturity, and the lignin content of stems is consistently higher than that of leaves (Mowat et al, 1969; Kilcher and Troelsen, 1973).

2.2. FACTORS AFFECTING DIGESTIBILITY OF STRAW

The composition of straw affects the amount of the total energy which is available to ruminants. Composition is largely determined by the maturity of the straw. Other factors such as level of feeding, physical form of the diet and dietary protein level and source may also affect the digestibility of straw.

2.2.1. Level of Feeding

When ruminants are fed high levels of roughages there is a close association between the level of feeding and the digestibility of the diet (Blaxter et al, 1961). Milne and Campling (1972) found a linear decline of 6 to 8% in digestibility when the intake of high quality hay was increased form 800 to 2000 g daily in sheep. In another experiment, a hay and concentrate diet (1:1 ratio) fed to

wethers resulted in a linear decline in organic matter digestibility from 74.4 to 68.6% as daily dry matter intake increased from 600 to 1400 g per day (Leaver et al, 1969). There is some evidence that digestibility decreases more with poor quality feeds, such as straw, when intake is increased (ARC, 1965).

Experiments have demonstrated that increased levels of feeding result in increased rates of passage through the rumen (Blaxter et al, 1956). This in turn causes the observed decrease in digestibility since the feedstuffs are exposed to rumen microbial degradation and digestive enzymes for a shorter period of time.

2.2.2. Mechanical Processing

Ruminants normally consume forages in the long or coarsely chopped form, and by a combination of mastication and fermentation these are reduced in the alimentary tract to a finely divided state. The surface area and fermentation rate of forages are increased by mechanical grinding (Pigden and Heaney, 1969). Feeding high levels of ground material tends to allow the feed to pass through the rumen more quickly. This reduces the time that feed particles are exposed to rumen micro-organisms and the digestibility of the feed is lowered (Blaxter et al, 1956).

Pelleted roughages have been shown to be less digestible than the same material in the long or chopped form, when fed to ruminants. Milne and Campling (1972) found that the digestibility of chopped grass hay was

significantly greater than that of pelleted hay, and that there was a highly significant linear decline in organic matter digestibility as the proportion of pellets in the diet increased.

The extent of depression in digestibility can be quite marked. Pigden and Heaney (1969), for example, cite crude fibre digestibilities of 72 and 54% for medium quality timothy, and 46 and 31% for mature timothy in chopped and pelleted forms, respectively. Similarly, Greenhalgh and Reid (1973) found that low quality hay fed in the long form had a digestibility of 65.7% compared to 54.1% for the same hay fed in the pelleted form. Reduction in digestibility due to pelleting has also been reported by other researchers (Wallace et al, 1961; Alwash and Thomas, 1971; Beever et al, 1972; Greenhalgh and Reid, 1974).

There is little difference between the digestibility of ground and pelleted forages. Apparent digestibilities of 58.5 and 54.3% were obtained for pelleted and ground diets, respectively, containing 30% wheat straw (Levy et al, 1972). Cloete and Rossouw (1970) found no differences in apparent digestibility between pelleted and ground diets. These results indicate that particle size is more important in determining digestibility than is the final physical form of the feedstuff.

Pelleting or grinding may also affect the sites of digestion. In an experiment with sheep, the apparent digestibility of the gross energy of chopped, ground and pelleted roughage was similar at a maintenance level of

feeding but digestion within the small intestine was markedly greater for the ground and pelleted than for the chopped diet (Thomson et al, 1972).

2.2.3. Protein Level

It has generally been found that protein supplementation improves the digestibility of both organic matter and crude fibre when a protein deficiency exists. Results obtained by Whitelaw et al (1961) and Lyons et al (1970) indicate that this is true regardless of the type of diet which is fed.

The amount of crude protein required to stimulate maximum digestion of low quality roughage diets has been examined by several workers. Biuret added to a hay-based diet containing 4.5% crude protein increased organic matter digestibility from 48.3 to 56.4% when the crude protein level was increased to 7.4%. A further increase from 7.4 to 12.2% crude protein resulted in no additional improvement in digestibility in an experiment conducted by Fick et al (1973). Lyons et al (1970) found that crude fibre digestibility increased from 56.9 to 61.4% when the protein level was raised from 5.3 to 7.1% in diets containing two-thirds barley straw. A further increase to 9.2% crude protein in the diet, in this instance, raised the crude fibre digestibility by 2.1 percentage points.

In a trial with oat straw containing 2 to 3% crude protein fed at 80 to 85% of the diet, Fishwick et al (1973) found that fibre and dry matter digestibility increased up to the 9%

crude protein limit of the trial. Again it was found that, as in a production function, the first addition of protein produced the greatest increase in digestibilty.

2.2.4. Protein Source

Rumen micro-organisms can utilize non-protein nitrogen as a nitrogen source for protein synthesis (Hungate, 1966). Urea is the major source of non-protein nitrogen in general use for cattle and sheep. Unfortunately, the release of ammonia from urea is so rapid that it may not be an effective supplement for low protein roughages in some instances (Milligan and Young, 1972). They obtained results which indicated that non-protein nitrogen supplements may actually reduce dry matter digestibility under some circumstances.

Swan and Lamming (1968) found that the dry matter digestibility of a diet containing 30% barley straw was only 70.2% when urea was used as a supplement, but was 75.3% when soybean meal was used as a supplement for wethers. Bhattacharya and Pervez (1973), however, reported that there was no effect on dry matter or crude fibre digestibilty when 0 or 2% urea replaced soybean meal in a 50% wheat straw diet. The evidence as to whether non-protein nitrogen supplements are as effective as plant proteins in improving digestibility of organic matter in protein deficiencey situations is thus inconclusive.

2.2.5. Supplemental Energy

Straw is a relatively low energy feedstuff, thus

additional sources of energy are normally fed in conjunction with straw in a diet. Often the source of energy is a cereal grain which has a high starch content. In such cases decreases in the digestibility of fibre may occur. In sheep, for example, the addition of 0, 60 or 120 g/day of starch and sucrose to a diet consisting of 600 g of low quality hay and biuret and containing 8% crude protein, resulted in cellulose digestibilities of 55.8, 50.4 and 48.2%, respectively (Fick et al, 1973). Corresponding organic matter digestibilities were 52.2, 53.3 and 56.6%. Similarly, the addition of starch to a steer diet with a high fibre level (74% wood pulp) reduced acid detergent fibre digestibility from 52.3 to 49.3% while dry matter digestibility remained relatively constant at 55.9 and 55.7% (Slyter et al, 1971b).

In contrast to these results with purified starch or sugar, the addition of 15% barley to a barley straw diet did not affect the dry matter digestibility of straw fed to sheep (Kay et al, 1968b). Apparent digestibility of the total diet increased from 36.0 to 44.8%. Watson et al (1939) also found that the addition of hay caused no reduction in fibre digestibility when it was added to a straw diet.

There is evidence that the reduced fibre digestibility when starch is fed, could be caused by a change in the rumen microbial population. Slyter et al (1971a) found that the inclusion of 13% starch in a diet reduced the number of cellulytic bacteria in the rumen and increased the total

number of rumen bacteria. Also, Hungate (1966) claims that the presence of sugar can inhibit the activity of cellulase *in vitro*.

2.3. FACTORS AFFECTING VOLUNTARY INTAKE OF STRAW

The amount of nutrients available to ruminants is a function of the digestibility and the consumption of the feedstuffs from which the nutrients are obtained. The voluntary intake of straw is limited by the capacity of the reticulo-rumen and by the rate of disappearance of digesta from this organ (Campling, 1969). The rate of disappearance of digesta depends on microbial activity in the reticulo-rumen, the composition of the feed and particle size of the feed.

2.3.1. Rumen Capacity

Numerous experiments have been carried out to investigate how feed intake changes in response to changes in the volume of rumen contents. Transfer of ruminal digesta from a donor animal (Campling and Balch, 1961; Carr and Jacobson, 1967), intraruminal addition of feed (Greenhalgh and Reid, 1971) or removal of digesta from the rumen (Campling and Balch, 1961; Carr and Jacobson, 1967) have all resulted in some compensation in feed intake. There is evidence that this effect is mediated by tension receptors in the ruminant stomach (Iggo and Leek, 1969).

2.3.2. Level of Low Quality Forage in the Diet

McCullough (1969) fed levels of long hay ranging from 0 to 40% to steers. As the proportion of hay in the

diet increased, total intake increased up to a 20% level of hay, after which intake decreased indicating that although a certain amount of roughage stimulates intake, greater amounts cause a decrease in total intake. In a subsequent study, McCullough (1970) found no significant differences in voluntary intake patterns of animals fed high or low quality hay.

Total feed intake of wintering cows decreased when the proportion of oat straw in the diet was increased from 72 to 86% (Mathison, 1974b). The intake of straw, however, remained constant. Andrews et al (1972) also found that when adequate protein was present in the diet there was no change in straw intake when the percentage of barley straw fed was increased from 62 to 73%. Similarly, Blair et al (1974) found significant decreases in total intake as wheat straw levels increased from 17.5 to 47.5% in diets for lactating dairy cows. Owen et al (1969a) observed that voluntary intake of lambs was uniformly depressed with increased dilution of the diet when ground oat husks were added up to 60% of the diet. Bines and Davey (1970), however, found no significant difference in intake among non-lactating cows as a result of feeding from 20 to 60% chopped straw in their diet.

It would thus appear that intake will be depressed when the level of low quality roughage in the diet is increased. With high roughage diets, however, the addition of small amounts of concentrate does not appear to affect the daily

consumption of straw.

2.3.3. Physical Form of the Diet

The effect of the physical form of forage-based diets on voluntary intake of ruminants has been observed by Wallace et al (1961), Knox et al (1964), Nicholson and Cunningham (1964), Wilkins et al (1972), Greenhalgh and Reid (1973,1974) and Mathison (1974a). All these workers found that as the particle size of the forage consumed decreased, voluntary intake increased. This effect appeared to be most pronounced when low quality forages were fed (Minson, 1963; Greenhalgh and Reid 1973). In the Greenhalgh and Reid (1973) study the intake of a low quality hay nearly doubled, while the intake of a high quality hay increased only by approximately one-third when the diets were fed in the pelleted form instead of the chopped form. The use of pelleted diets instead of ground diets of the same particle size has resulted in variable effects on voluntary intake. Botkin et al (1957), Cloete and Rossouw (1970) and Beacom et al (1973) observed increases due to pelleting, while Knox et al (1964) and Levy et al (1972) found decreased consumption of pelleted diets relative to ground diets.

Grinding can reduce particle size to the point where the feed particles are small enough to pass the reticulo-omasal orfice immediately after entering the rumen (Pigden and Heaney, 1969). In such cases the particles need only absorb moisture to allow them to sink, thereby shortening the residence time of particles in the rumen. This in turn

would be expected to lead to increased voluntary consumption.

2.3.4. Protein Level of the Diet

Nitrogen is required by rumen micro-organisms for metabolism and growth (Hungate, 1966). In low protein diets additional nitrogen may stimulate increased microbial growth and rate of digestion in the rumen. Increases in digestion and passage rates in turn stimulate increased voluntary intake of low quality roughages (Coombe and Tribe, 1963; Pigden and Heaney, 1969).

Numerous experiments have been conducted with sheep showing the effect of nitrogen supplementation on intake. Voluntary intake of poor hay increased from 510 to 760 g/day when supplemental urea was increased from 0 to 12 g/day in sheep (Pieterse et al, 1966). Jones et al (1973) reported that voluntary intake increased as crude protein was increased from 5 to 20% for wethers. With ewes, however, intake did not respond to crude protein levels beyond 10%. Coombe and Tribe (1963) found that urea added to the straw and molasses diets of sheep increased voluntary intake until the animals were in positive nitrogen balance. Beyond that level additional dietary nitrogen was excreted in the urine.

Straw intake of steers was not affected by the addition of 75 g of urea, or urea and 1.36 kg of barley daily when a diet consisting of about 75% straw was fed (O'Donovan, 1968). Similarly, Kay et al (1968a) found little evidence

of improvement in intake of barley straw (5 to 7% crude protein) when supplemented with a source of dietary nitrogen (urea). Lyons et al (1970) found that daily allowances of 1.37 kg of concentrate providing 4.83, 5.82, 7.20 or 9.91% crude protein in the diet of cattle resulted in a 25% increase in intake as crude protein increased to 5.82%, with no further increases at higher levels. Similarly, in work reported by Fishwick et al (1973) the oat straw intake increased by 20% when crude protein was increased to 6%. Higher protein levels stimulated no further increases. Wintering cows supplemented with protein increased voluntary consumption of brome grass hay (Clanton and Zimmerman, 1965). However, in one year when the crude protein of the hay was 8.4% non-supplemented cows consumed more than supplemented cows.

In summary, it appears that cattle receiving low quality roughage diets, such as straw, will increase intake markedly until the crude protein level of the diet reaches the 6% range. Sheep may require 2 or 3% more protein, 8 or 9% total crude protein, in their diet to reach near maximal intake. Beyond these levels, further increases in intake are small or nonexistant.

2.4 UTILIZATION OF STRAW IN MAINTENANCE DIETS

Straw can constitute a major portion of a maintenance diet for cows (Morrison, 1956). Recent research information on the use of straw is somewhat limited. Some work has been carried out in Great Britain, along with a limited amount of research in Western Canada and the

United States.

Kay et al (1968a) reported body weight changes for cows of -0.19 and -0.29 kg/day during the final 5 months before calving in two consecutive winters as a result of the daily consumption of 7.4 to 7.5 kg of long barley straw and 2 kg of barley. No health problems were noted nor were any calving difficulties encountered, and although birth weights were lower than average in the first year of the trial, the calves were vigorous. In the second year, birth weights averaged 34 kg, 4 kg heavier than the previous year. These birth weights were considered to be normal for the calves in the study. The cows had regained their winter weight loss and their weight loss at calving by the time they were rebred 10 weeks after calving and no rebreeding problems were encountered.

Ball et al (1971) conducted a study in which a set of cows, beginning as heifers, were used in a series of trials completed in three consecutive years. During the wintering period from the first of November to the last week in April, the cows were fed diets containing 76 to 82% barley straw. The energy and protein supplements used varied from year to year but diets were equated in terms of energy. Barley and urea were the major supplements used.

There was very little difference in performance among diets with losses averaging 55 kg during the 175 to 180 day winter feeding periods which included the calving period. The weight loss was more than recovered during the

summer grazing season resulting in an average 45 to 50 kg yearly weight gain, with the exception of the first year, when the heifers only regained the weight lost over winter.

Reproductive performance was very acceptable. In the third year of the trial, 10% of the cows conceived late and were replaced to maintain the calving period. In the other years, all 40 cows in the trial rebred in a 3 month breeding program. No health problems occurred in the cows in the study. Birth weights of the calves averaged about 35 kg and average daily gain from birth to weaning at 4 months was about 0.9 kg. No control treatment groups were included in this study, so comparisons with other feedstuffs were not possible.

Johnson (1972) fed diets high in oat straw to thin beef cows at Saskatoon. Two of 48 cows fed diets containing 89 to 91% straw subsequently died of abomasal impaction. This condition was described by Blood and Henderson (1963) as the blockage of the pylorus by fragmented, undigested straw that has passed from the rumen. The clinical syndrome is similar to that of vagus indigestion. Johnson (1972) concluded that the conditions most likely to cause abomasal impaction are low quality feed, thin cows, the onset of cold weather and an increase in feed intake. Following the deaths, the amount of straw in the diet was reduced to 2.7 kg/day for the maintenance period, and 4.6 kg/day during the late gestation and lactation period of the study. Comparisons between a straw and grain diet and a hay and grain diet

revealed non-significant differences in weight gains, backfat changes or milk production for the cows, or in sex-adjusted average daily gains of the calves. However, the interval to conception was 13 days longer for the cows on the straw treatment. This was partially due to a 7 day delay to first estrus. It was suggested that this delay was due to the stress of lactation and nutritional inadequacies of the straw diet.

Cows voluntarily consumed 8.4 to 8.9 kg of oat straw in addition to 1.4 to 3.2 kg of concentrate daily in a trial conducted by Mathison (1974b), and this resulted in average daily gains of from 0.17 to 0.50 kg. No major change in straw intake could be attributed to differences in length of straw cut, level of supplementary energy intake or the addition of molasses or a liquid non-protein nitrogen supplement to the straw. In another study, (Mathison, 1974a) cows receiving 81 to 89% barley straw gained 0.29 kg/day when cut straw was fed and 0.62 kg when pelleted straw was fed.

Straw can be used as a major portion of wintering beef cow maintenance diets with no noticeable effects on reproductive and productive characteristics. In most situations no health problems will result, although under the conditions outlined by Johnson (1972) abomasal impaction may be a problem.

2.5. UTILIZATION OF STRAW IN GROWING AND FATTENING DIETS

Straw has been used in research trials of growing and fattening diets for feedlot animals at levels of up to 70%. The results of these trials are summarized in Table 1.

All workers found decreased feed conversions as the levels of straw in the diet increased, however, the corresponding decreases in average daily gain were much less apparent. The average daily gains of 1.29, 1.19 and 1.02 kg for steers fed diets composed of 30, 50 and 70% barley straw, respectively, by Swan and Lamming (1970) suggest that acceptable levels of performance can be obtained using high levels of straw. The relative costs of feedstuffs should determine the level of straw used in the diet. The level of straw fed will also be modified by the non-feed costs, since these costs are reduced when daily gain increases.

TABLE 1. Average daily gain and feed conversion of steers fed different levels of straw

Source	Type of straw	% Straw	Average daily gain (kg)	Feed conversion (kg feed/kg gain)
Kay et al (1979a)	Barley	5	1.18	4.8
Forbes et al (1969a)	Barley	10	1.08	6.46
Raven et al (1969)	Barley	10	.99	7.80
Lofgreen and Christensen (1962)	Barley	15	.85	--
Nicholson (1967)	Oat	20	1.50	7.60
Forbes et al (1969a)	Barley	20	.97	7.61
Forbes et al (1969b)	Barley	20	.78	10.50
Raven et al (1969)	Barley	20	.91	7.70
White and Reynolds (1969)	Rice	20	1.23	7.20
Kay et al (1970a)	Barley	20	.99	5.50
Lofgreen and Christensen (1962)	Barley	25	.59	--
Nicholson (1967)	Oat	30	1.39	8.22
Forbes et al (1969a)	Barley	30	.92	7.31
Raven et al (1969)	Barley	30	.81	8.30
Kay et al (1970b)	Barley	30	1.04	6.70
Swan and Lamming (1970)	Barley	30	1.29	7.40

TABLE 1. (continued)

Source	Type of straw	% Straw	Average daily gain (kg)	Feed conversion (kg feed/kg gain)
Kay et al (1970a)	Barley	35	.85	6.90
Nicholson (1967)	Oat	40	1.39	8.78
Forbes et al (1969a)	Barley	40	.73	8.49
Forbes et al (1969b)	Barley	40	.58	13.60
White and Reynolds (1969)	Rice	40	1.09	8.60
Forbes et al (1969a)	Barley	50	.65	10.00
Kay et al (1970a)	Barley	50	.67	8.30
Kay et al (1970b)	Barley	50	.87	7.10
Swan and Lamming (1970)	Barley	50	1.19	8.10
Swan and Lamming (1970)	Barley	70	1.02	9.80

3. EXPERIMENT I. STRAW IN MAINTENANCE DIETS

This experiment was primarily designed to evaluate the effects of physical form and protein content of diets containing large amounts of barley straw on the performance of wintering dry pregnant beef cows. Straw based diets containing barley based N-glucosyl ureide (BBGU), hay and different amounts of concentrate were also evaluated in this experiment.

3.1. MATERIALS AND METHODS

3.1.1. Design of the Experiment

The experiment was designed to include 60 pregnant cows, in 15 different treatment groups, such that there were four cows per group. These cows were allotted to their respective treatments on the basis of weight, age and breed, so that animals among treatments were as uniform as possible.

Twelve groups of cows (36 animals) were used to evaluate the effects of pelleting (P), grinding (G) and chopping (C) straw in diets containing low (LP), medium (MP) and high (HP) protein levels in a three by three by two by two nested factorial experiment (Table 2).

In another facet of the experiment 12 cows were assigned to chopped straw diets in which the concentrate contained three levels of BBGU (Mathison et al, 1974) (Table 3). This part of the experiment was analyzed as a two by three by two by two nested factorial experiment, using the 12 cows

TABLE 2. Formulation and composition of diets used in the study of the effects of protein level and physical form of the diet

Feedstuff[1]	Protein level		
	Low	Medium	High
Barley straw	86.0	86.0	86.0
Barley	13.1	10.2	3.0
Soybean meal	--	2.8	10.0
Calcium-phosphate (18:20.5)	0.25	0.25	0.25
Trace mineral salt	0.50	0.50	0.50
Vitamin premix[2]	0.22	0.22	0.22
	100.07	99.97	99.97
Analyzed composition (moisture-free basis)			
Pelleted diets			
Dry matter (%)	93.1	93.1	93.3
Acid detergent fibre (%)	43.9	46.3	43.1
Crude protein (%)	6.0	6.4	9.4
Calcium (%)	0.54	0.44	0.65
Phosphorus (%)	0.22	0.21	0.26
Ground diets			
Dry matter (%)	93.0	93.3	93.1
Acid detergent fibre (%)	46.0	46.0	43.1
Crude protein (%)	5.4	6.6	9.4
Calcium (%)	0.40	0.43	0.65
Phosphorus (%)	0.22	0.24	0.26
Chopped diets			
Dry matter (%)	92.9	93.2	93.0
Acid detergent fibre (%)	44.2	44.2	44.3
Crude protein (%)	5.7	6.9	10.3
Calcium (%)	0.46	0.49	0.50
Phosphorus (%)	0.21	0.23	0.25

[1]Expressed as % in total diet on a moisture-free basis.

[2]Each kg of premix contained 2,000,000, 350,000 and 2,000 IU of Vitamin A, D and E respectively.

TABLE 3. Formulation and composition of the diets containing barley based N-glucosyl ureide

Feedstuff[1]	Protein level		
	Low	Medium	High
Barley straw	86.0	86.0	86.0
Barley	13.1	10.8	5.2
Barley based N-glucosyl ureide	--	2.2	7.9
Calcium-phosphate (18:20.5)	0.25	0.25	--
Limestone	--	--	0.15
Trace mineral salt	0.50	0.50	0.50
Vitamin premix[2]	0.22	0.22	0.22
	100.07	99.97	99.97
Analyzed composition (moisture-free basis)			
Dry matter (%)	92.9	92.9	92.7
Acid detergent fibre (%)	44.2	44.2	44.2
Crude protein (%)	5.7	6.7	9.9
Calcium (%)	0.47	0.46	0.50
Phosphorus (%)	0.24	0.21	0.26

[1]Expressed as % in total diet on a moisture-free basis.

[2]Each kg of premix contained 2,000,000, 350,000 and 2,000 IU of Vitamin A, D and E respectively.

mentioned previously which received chopped straw and soybean meal, to obtain a comparison of the effect of the source of protein on cow performance.

Eight more cows (two groups) were assigned to a low and a high straw pelleted diet. These diets contained 78 and 94.2% straw respectively (Table 4). The performance of these cows was compared to the four animals used in the main part of the experiment which received the 86% pelleted medium protein diet in a three by four nested factorial experiment.

The remaining four cows were assigned to a pelleted diet which contained 78% straw and 22% mixed hay (Table 4). The performance of these cows was also compared to the cows in the main part of the experiment which received the pelleted medium protein diet containing 86% straw in a two by four nested factorial experiment.

The experiment commenced on December 7, 1974 and the feeding trial finished on March 21, 1975. The period from December 7 to 20, 1974 was considered to be a stabilization period. Similarly, during the period from March 14 to 21, 1975 hay was fed to all cows to determine the change in gastro-intestinal fill on the various treatments.

3.1.2. Experimental Diets

The formulation and composition of the diets used in this experiment are given in Tables 2, 3 and 4. The barley straw used in these diets could be classed as average to good quality since it contained 4.9 to 5.3% crude protein on a moisture-free basis.

TABLE 4. Formulation and composition of the high and low straw diets and the hay diet

Feedstuff[1]	Straw level		
	Low	High	Hay
Barley straw	78.0	94.2	78
Mixed hay[2]	--	--	22
Barley	19.9	--	--
Soybean meal	1.2	4.8	--
Calcium-phosphate (18:20.5)	0.20	0.35	--
Trace mineral salt	0.50	0.50	--
Vitamin premix[3]	0.22	0.22	--
	100.00	100.00	100.0
Analyzed composition (moisture-free basis)			
Dry matter (%)	93.3	93.2	92.7
Acid detergent fibre (%)	40.5	46.1	48.9
Crude protein (%)	7.1	7.6	6.3
Calcium (%)	0.47	0.56	0.62
Phosphorus (%)	0.24	0.25	0.13

[1]Expressed as % in total diet on a moisture-free basis

[2]Average quality mixed hay (13.5% crude protein) containing only clover and brome.

[3]Each kg of premix contained 2,000,000, 350,000 and 2,000 IU of Vitamin A, D and E respectively.

The pellets used in the study were prepared as a complete diet at a commercial plant by grinding straw and concentrate through a 4.8 mm screen and then pelleting with a 6.4 mm die. These pellets were prepared about 3 weeks before the start of the experiment. Ground straw was processed at the experimental site through a Bear Cat hammer mill equipped with a 4.8 mm screen. A New Holland forage harvester was used to chop straw, and the resulting product averaged 60 to 70 mm in length. The ground and chopped straw were obtained from the same source as that used for the pellets. This material was prepared as needed during the experiment. The concentrate portions of the diet were prepared at the University of Alberta feed mill about 1 month before the start of the experiment.

For analysis purposes three composite samples were collected for each diet used in the experiment. Each composite sample was composed of a mixture of samples taken on three different occasions. The samples were finely ground with a Christy-Norris mill before analysis.

3.1.3. Experimental Site and Facilities

The experiment was conducted at the University of Alberta, Beef Cattle Nutrition Unit at the Ellerslie Research Station. The cows were kept in 12 pens at the facility. Each pen, which accommodated five cows, measured approximately 4.0 by 7.6 m. Wind protection and overhead shelter was provided by the open front shed, which covered about one-third of each pen. A heated watering bowl connected to the

underground water system was located between each two pens, so that ten cows had access to each watering bowl.

Each pen was equipped with six stanchions, five of which were used to confine the cows individually during the feeding periods. The sixth remained open to allow ad libitum access to salt and mineral when the cows were not confined. Similarly, the concrete feed bunk in front of each pen contained five feed boxes to allow for measurement of the feed consumption of individual animals.

The scale for weighing the cows and the cattle squeeze for restraining the animals during blood sampling and medical treatment were located directly adjacent to the feeding barns.

3.1.4. Animals and their Management

To achieve the prescribed conditions of the design, a group of 60 cows which had been pregnancy tested by the staff at the ranch were selected from the University of Alberta beef breeding herd (Berg, 1975). The cows were from 2 to 10 years of age. The breed composition consisted of ten purebred Hereford cows and 50 cross breds involving the Angus, Brahman, Brown Swiss, Charolais, Galloway and Hereford breeds (Berg, 1975). Hair coat colours were variable. The live-weights of the cows ranged from 375 to 592 kg, with a mean of 486 kg, on November 27, 1974, 5 days after the cows arrived at the experimental site from the University of Alberta ranch at Kinsella.

A 1:1 mixture of calcium-phosphorus mineral and

trace mineral salt was offered on an *ad libitum* basis. A 2 ml dose containing 1,000,000 IU of Vitamin A; 150,000 IU of Vitamin D and 1,000 IU of Vitamin E was given intramuscularly on November 27, 1974. Water was available *ad libitum* except during the time of confinement for feeding and prior to weighing.

From December 6, 1974 until March 21, 1975 all experimental cows were managed similarly. Each cow was offered her daily diet in an individual stanchion and was allowed 2 to 3 hours each morning and afternoon (between 0800 and 1130 hours and between 1330 and 1630 hours) to consume the feed. Wood shavings were provided as bedding. Following the experimental feeding trial the cows were transported back to the University of Alberta ranch where they were subsequently returned to, and managed with, the main herd (Berg, 1975).

3.1.5. Measurements

3.1.5.1. Climatic conditions

Daily minimum and maximum temperatures were obtained from the Atmospheric Environment Service at the Edmonton International Airport located 15 km south of the experimental site. Routine temperature checks indicated that there was little variation between these temperatures and those obtained at the experimental site. Daily mean temperatures were calculated as the mean of the maximum and minimum for the day. Degree days, as a measure of cold stress, were calculated by totalling the number of degrees the mean daily temperature

was below -15 C during the test period and dividing by the number of days in the period (Dietz, 1971). The value of -15 C was selected as it approximates the likely critical temperature of the type of animals in the experiment (Webster et al, 1970).

3.1.5.2. Feed, energy and protein intake

The cows were fed an amount such that some of the feed offered remained after the feeding period on most days. The feed required for feeding that afternoon and for the following morning was weighed and recorded as one amount each day. Once a week the feed remaining after feeding was weighed and removed from the individual cow's feed box. The weekly feed intake for each cow was calculated by adding daily feed provided and subtracting the feed weighed back.

The daily digestible energy intake of cows in the physical form and protein level study was calculated by multiplying the daily feed intake by the digestible energy concentration of the diet as determined by digestibility trials using sheep. As all nine diets were not included in the digestibility trials, the digestibility of gross energy for the pelleted and chopped diets at the low and medium protein levels was assumed to be decreased by the same proportion as was found for the low and medium protein levels in the protein level study using the ground straw diets.

The daily digestible crude protein intake was calculated by multiplying the crude protein intake by the

% digestibility of nitrogen found in the digestibility trials, using the same type of adjustments as had previously been used in the energy calculations.

In the protein source and level trial, the daily digestible energy intake was calculated by multiplying daily consumption of cows by the digestible energy concentrations of the chopped straw diets, as previously determined in the digestibility trials. It was assumed that there was no difference in digestibility due to protein source (Martin, 1976). The digestible energy concentration used for the calculations in the straw level trial were NRC (1969) average values for the concentrate portion and the value calculated for pelleted straw from the digestibility trial for the straw portion of the diet.

3.1.5.3. Cow weights

The cows were weighed at weekly intervals during the experiment with the exception of January 3, 1975 and March 7, 1975. In the former case, the water supply had been restricted for 2 days before the regular weigh date, as repairs were being made to the water lines. In the latter case, feed had been restricted to the animals during 2 of the 4 days before the scheduled weighing to facilitate collecting blood samples and attempting to collect rumen fluid samples. In addition, the cows were weighed on 2 consecutive days when the test commenced and upon its conclusion. In every case, the weights were taken in the

morning before feeding and after the cows had been kept away from water for 16 hours.

3.1.5.4. Change in gastro-intestinal fill

The change in weight of individual cows during the first 2 weeks on the test diets was calculated to obtain an assessment of the effects of high straw diets on gastro-intestinal fill. The cows had previously been consuming about 8 kg of good quality hay per day. At the end of the trial the cows were again switched to a hay diet and the change in weight during this week was determined. It was assumed that the weight changes during these periods predominantly reflected change in gastro-intestinal fill.

3.1.5.5. Depth of subcutaneous fat

The depth of skin and subcutaneous fat were measured at four sites on each cow, using an ultrasonic probe (Krautkramer Ultrasonic Flow Detector, type U.S.M. 2). Measurements were made by the same operator on December 3, 1974 and on March 17, 1975. The measurement sites were at the 11th and 12th rib area at 8 and 15 cm from the dorsal medial line, on the shoulder and on the hip at 8 cm from the dorsal medial line. The mean fat depths were derived from the average of the four sites measured.

3.1.5.6. Blood constituents

Twenty ml of jugular blood were taken from each cow 11 days before the completion of the experimental feeding period. The blood samples were taken in the morning before feeding. Heparinized vacuum tubes and 20 gauge Vacutainer

needles were used to obtain the blood samples, which took about 2 minutes of restrained time per animal. Immediately following sampling, the samples were refrigerated at 2 to 3 C for 2 to 4 hours. The samples were then centrifuged to separate plasma and the plasma was removed with pasteur pipettes and stored frozen in plastic vials. The plasma samples were subsequently analyzed for plasma urea nitrogen and free fatty acids.

3.1.5.7. Post-calving information

The birth weight of each calf in the study was taken within 24 hours of birth. Cows were weighed at this time as well.

3.1.5.8. Digestibility of the diets

Digestibility measurements were carried out with sheep using ground straw and three dietary protein levels, and using the high protein diets prepared in the three different physical forms.

Twelve Suffolk wethers were individually housed in metabolism cages at the Metabolic Unit of the University Farm in Edmonton. Four sheep received each of the three diets tested at one time in a three by four nested factorial designed experiment. The experimental animals received the test diets in a once daily feeding each morning. The sheep were allowed 7 days to become accustomed to the diets offered. The level of feeding was then adjusted to provide one-half of the digestible energy required for the maintenance of each sheep. This was calculated using the formula presented

by the National Research Council (NRC, 1968), and the weight of the individual wether at the start of the trial. The sheep were fed at this level for 14 days.

During the last 6 days of the trial, the total feces produced by each sheep was collected and weighed once daily. Samples, representing a constant proportion of the daily fecal output of individual sheep, were dried in a force-draft oven at 55 C for 72 hours. Then the six samples for each sheep were combined to make one composite sample. Each sample was finely ground using a Christy-Norris grinding mill and was stored in a plastic sample cup.

3.1.5.9. Chemical analyses

The dry matter content of feed and feces samples was determined by the AOAC (1965) method. Gross energy in feed and feces was determined by means of a Parr oxygen bomb calorimeter. Cell wall content was determined by the neutral detergent fibre method of Goering and Van Soest (1970) as modified (Appendix I).

Acid detergent fibre, calcium, phosphorus and nitrogen analyses were carried out by the Alberta Soil and Feed Testing Laboratory in Edmonton. The method of Goering and Van Soest (1970) was used in the determination of acid detergent fibre. The acid detergent fibre contents of the concentrates were taken to be the average crude fibre content (NRC, 1970) divided by 0.85 (Martin, P.J., personal communication). Crude protein (N x 6.25) was determined by Technicon Methodology No. 218-72A.

3.1.6. Statistical Analyses

Analysis of variance and regression analysis were performed using computer programs available from the University of Alberta Computing Centre. In the case of missing data, the missing observation was taken as the mean of the remaining animals in the treatment (Hardin, R.T, personal communication) and the number of degrees of freedom for animals within treatments was decreased by one for each missing observation. The average number of observations per mean for calculating the standard error of the mean was calculated using the harmonic mean procedure of Winer (1971). Duncan's New Multiple Range Test (Steel and Torrie, 1960) was used in comparison of means.

3.2. RESULTS

3.2.1. Animal Health

Most of the animals remained healthy throughout the experiment. Two cows, however, died during the first half of the experimental period.

One cow on the ground, medium protein diet went off feed on December 24, 1974, three days after a blizzard. The cow showed rumen distention along with the other symptoms of abomasal impaction as outlined by Johnson (1972). The cow did not respond to treatment and died on January 1, 1975. The animal was submitted to the Alberta Veterinary Services lab for examination. Death was found to be related to atherosclerosis resulting in stoppage of blood flow to the rumen and cessation of rumen function. There was no evidence of abomasal impaction.

On January 19, 1975 a cow receiving the high straw, pelleted diet went off feed, and died the following morning. The diagnosis from the Veterinary lab was that death was related to extreme distension and size of the rumen, causing circulatory difficulties which would probably have resulted in disseminated intravascular coagulation due to impaired circulation.

One cow on the pelleted diet supplemented with hay continually refused to consume the diet on a regular basis. The cow appeared to remain healthy throughout the

trial. However, due to the poor feed consumption, the results of this cow's performance have not been included in the data.

Although the cows were pregnancy tested, three cows later proved to be non-pregnant. The results from these cows has been, however, included for all measurements except the post-calving data.

3.2.2. Climatic Conditions During the Experiment

The mean monthly temperature in December was 6.9 degrees above normal, making it the third mildest December since 1880. For much of January temperatures were above normal, with the exception of a cold period from January 7 to 12, 1975. February was colder than normal despite the mild conditions in the latter half of the month. The first half of March was also colder than normal with the coldest temperature for the month being recorded on March 10, 1975 (Prusak, W., Atmospheric Environment Service, personal communication). The mean daily temperature during the trial was -11.6 C as compared with -13.4 C in the trials of Dietz (1971). The number of degree days of cold stress was 30.4 compared with 16.3 in the Dietz (1971) trial.

3.2.3. Effects of Physical Form and Protein Level of Diet

During the trial it was observed that there was a wide degree of variation in weekly feed consumption for the cows receiving the P diets. Several of the cows, particularly those receiving the HP diets, refused to consume any feed for periods of 3 to 4 days at a time, at varying intervals throughout the study. This was evidenced by a highly significantly ($P < 0.01$) greater standard deviation of weekly feed intake for the P diets (Table 5). In addition the low intake produced low weight gains in the treatment group receiving the pelleted high protein diet. This resulted in a highly significant ($P < 0.01$) interaction between physical forms and protein levels (Appendix Table 1). Thus the data was also analyzed for protein effects when the P diets were excluded. This analysis showed no interaction between the G and C diets and protein concentration in the diet (Appendix Table 2). Both methods of analysis are included in the following tables.

The mean daily feed intakes of 10.7, 9.6 and 9.3 kg for the P, G and C diets, respectively, approached ($P < 0.10$) a significant difference (Table 5). When daily feed intake was expressed on a metabolic weight basis the P fed cows consumed significantly ($P < 0.05$) more feed than the cows fed C diets. The daily intake of digestible energy was 18.8, 15.6 and 17.7 Mcal for the cows fed P, G and C diets respectively. These intakes were significantly ($P < 0.05$) different from one another. No differences in

TABLE 5. Means and standard errors of feed, energy and protein intake and variation of feed intake on an as fed basis for cows fed straw-based diets in three physical forms at three protein levels

	Physical form			Protein level			Standard error
	Pelleted	Ground	Chopped	Low	Medium	High	
Daily feed intake (kg)	10.7^{a}	9.6^{a}	9.3^{a}	10.3^{a}	9.8^{a}	9.5^{a}	0.4
Daily feed intake (g/kg weight$^{0.75}$)	95^{a}	88^{ab}	84^{b}	93^{a}	89^{a}	87^{a}	2
Daily digestible energy intake (Mcal)	18.8^{a}	15.6^{b}	17.7^{ab}	17.7^{a}	17.0^{a}	17.4^{a}	0.7
Daily crude protein intake (kg)	0.71^{a}	0.63^{a}	0.66^{a}	0.55^{b}	0.60^{b}	0.86^{a}	0.03
Daily digestible crude protein intake (kg)	0.25^{a}	0.27^{a}	0.28^{a}	0.12^{c}	0.21^{b}	0.47^{a}	0.01
Standard deviation of weekly feed intake (kg)	12.4^{a}	6.8^{b}	6.7^{b}	7.7^{a}	8.4^{a}	9.7^{a}	0.8

a-c Superscripts in the same row of each section indicate values that are not significantly ($P < 0.05$) different when the same letter appears.

protein intake were found.

There were no significant differences in daily feed intake of the cows fed diets containing different amounts of supplemental protein when this was determined on the basis of actual consumption or on a metabolic weight basis, nor was there difference in digestible energy intake when the P diets were either included in or excluded from the analysis (Tables 5 and 6).

The differences in the change in gastro-intestinal fill at the start and the end of the feeding trial due to either physical form of the straw or dietary protein concentration were not significant (Tables 7 and 8). The change in fill was less at the end of the trial than at the start, with the mean changes being 23 and 32 kg, respectively.

Differences in cow weight changes after the time when fill adjustment had taken place to the end of the straw feeding period caused by the different physical forms of the straw were highly significant ($P < 0.01$) with mean gains being 34, 21 and 16 kg for the P, G and C diets, respectively (Table 7). Increased dietary protein concentration resulted in more winter weight gains in the cows (Table 8).

There were no significant differences in calf birth weights or in the weight changes of the cows from start of test to post-calving due to either physical form of the straw or dietary protein level (Tables 7 and 8).

Subcutcutaneous fat depths were not significantly affected by the treatments for either the initial or the

TABLE 6. Means and standard errors of feed, energy and protein intake on an as fed basis for cows fed straw-based diets at three protein levels[1]

	Protein level			Standard error
	Low	Medium	High	
Daily feed intake (kg)	9.9^{a}	8.9^{a}	9.5^{a}	0.4
Daily feed intake (g/kg weight$^{0.75}$)	90^{a}	82^{a}	87^{a}	3
Daily digestible energy intake (Mcal)	17.0^{a}	15.5^{a}	17.5^{a}	0.8
Daily crude protein intake (kg)	0.51^{b}	0.56^{b}	0.87^{a}	0.03
Daily digestible crude protein intake (kg)	0.12^{c}	0.21^{b}	0.50^{a}	0.02

[a] Superscript in the same row indicates values that are not significantly ($P < 0.05$) different.

[1] Not including the results from feeding the pelleted diets.

TABLE 7. Means and standard errors of weights, weight changes, changes in gastro-intestinal fill of cows and birth weights of calves resulting from straw-based diets being fed to cows in three physical forms at three protein levels

	Physical form			Protein level			Standard error
	Pelleted	Ground	Chopped	Low	Medium	High	
Initial weight (kg)	523^{a}	512^{a}	521^{a}	529^{a}	517^{a}	510^{a}	20
Weight change[1] (kg)	34^{a}	21^{b}	16^{b}	15^{c}	31^{a}	24^{b}	2
Increase in gastro-intestinal fill at start of test (kg)	33^{a}	33^{a}	30^{a}	35^{a}	27^{a}	34^{a}	5
Decrease in gastro-intestinal fill at end of test (kg)	24^{a}	27^{a}	19^{a}	21^{a}	25^{a}	24^{a}	3
Weight loss from December 6 to post-calving (kg)	30^{a}	39^{a}	45^{a}	39^{a}	40^{a}	34^{a}	8
Calf birth weight (kg)	42^{a}	40^{a}	39^{a}	41^{a}	40^{a}	40^{a}	2

[a-c] Superscripts in the same row of each section indicate values that are not significantly ($P < 0.05$) different when the same letter appears.

[1] For the 84 day period from December 20 to March 14. This does not include the first 14 days of the straw feeding period.

TABLE 8. Means and standard errors of weights, weight changes, changes in gastro-intestinal fill of cows and birth weights of calves resulting from straw-based diets being fed to cows at three protein levels[1]

	Protein level			Standard error
	Low	Medium	High	
Initial weight (kg)	523^{a}	518^{a}	509^{a}	18
Weight change[2] (kg)	10^{c}	16^{b}	29^{a}	2
Increase in gastro-intestinal fill at start of test (kg)	31^{a}	29^{a}	34^{a}	5
Decrease in gastro-intestinal fill at end of test (kg)	18^{a}	23^{a}	28^{a}	4
Weight loss from December 6 to post-calving (kg)	35^{a}	57^{a}	34^{a}	10
Calf birth weight (kg)	40^{a}	40^{a}	39^{a}	3

a-c Superscripts in the same row indicate values that are not significantly ($P < 0.05$) different when the same letter appears.

1 Not including the results from feeding the pelleted diets.

2 For the 84 day period from December 20 to March 14. This does not include the first 14 days of the straw feeding period.

final measurement (Tables 9 and 10). The mean fat depth of all cows at the start of the trial was 4.0 mm and at the end was 3.7 mm so that there was a slight loss of fat depth during the trial. Changes in fat depth caused by physical form of the diet (Table 9) or protein levels (Tables 9 and 10) were also not significant.

No significant differences were found among the treatments for the level of plasma free fatty acids, although slightly higher levels were observed in cows fed C diets than in the cows fed P or G diets (Table 9). Also, slightly higher free fatty acid levels were measured in the cows fed LP diets than in the MP or HP diets when the P diets were included (Table 9). When the P diets were excluded, the MP diet had the highest free fatty acid level (Table 10) although this difference was not significant.

There were no significant differences in the levels of plasma urea nitrogen of the cows due to the physical form of the straw (Table 9). In contrast, the urea nitrogen level increased ($P < 0.01$) as the level of dietary protein increased.

There were highly significant ($P < 0.01$) differences in dry matter digestibilities of the diets due to the different physical forms of the straw (Table 11). The mean values were 42.6, 53.1 and 49.0% for the P, G and C diets, respectively. Highly significant ($P < 0.01$) differences were also found in the digestibilities of gross energy, cell walls, acid detergent fibre and nitrogen. In all cases

TABLE 9. Means and standard errors of fat depths, fat depth changes, plasma free fatty acid and urea nitrogen concentrations of cows fed straw-based diets in three physical forms at three protein levels

	Physical form			Protein level			Standard error
	Pelleted	Ground	Chopped	Low	Medium	High	
Initial fat depth (mm)	3.8^{a}	3.9^{a}	4.2^{a}	3.7^{a}	4.0^{a}	4.2^{a}	0.5
Final fat depth (mm)	3.9^{a}	3.2^{a}	3.8^{a}	3.3^{a}	3.6^{a}	4.1^{a}	0.4
Fat depth change (mm)	$+0.1^{a}$	-0.7^{a}	-0.4^{a}	-0.4^{a}	-0.4^{a}	-0.1^{a}	0.4
Plasma free fatty acids (μ moles/ml plasma)	0.69^{a}	0.58^{a}	0.80^{a}	0.81^{a}	0.65^{a}	0.62^{a}	0.10
Plasma urea nitrogen (mg/100 ml plasma)	20.4^{a}	21.6^{a}	25.3^{a}	13.5^{b}	18.1^{b}	35.7^{a}	1.6

a-b Superscripts in the same row in each section indicate values that are not significantly ($P < 0.05$) different when the same letter appears.

TABLE 10. Means and standard errors of fat depths, fat depth changes, plasma free fatty acid and urea nitrogen concentrations of cows fed straw-based diets at three protein levels[1]

	Protein level			Standard error
	Low	Medium	High	
Initial fat depth (mm)	3.9^{a}	4.1^{a}	4.2^{a}	0.7
Final fat depth (mm)	3.5^{a}	3.3^{a}	3.8^{a}	0.5
Fat depth change (mm)	-0.4^{a}	-0.7^{a}	-0.4^{a}	0.4
Plasma free fatty acids (μ moles/ml plasma)	0.66^{a}	0.82^{a}	0.60^{a}	0.12
Plasma urea nitrogen (mg/100 ml plasma)	14.1^{b}	18.8^{b}	37.4^{a}	1.9

[a-b] Superscripts in the same row indicate values that are not significantly ($P < 0.05$) different when the same letter appears.

[1] Not including the results from feeding the pelleted diets.

TABLE 11. Means and standard errors of dry matter, gross energy and crude protein intake, and of apparent digestibilities for sheep fed pelleted, ground and chopped diets[1]

	Pelleted	Ground	Chopped	Standard error
Daily intake				
Dry matter (g)	503^{a}	511^{a}	490^{a}	19
Gross energy (Mcal)	2.19^{a}	2.25^{a}	2.15^{a}	0.08
Crude protein (g)	49.3^{ab}	53.6^{a}	45.6^{b}	1.8
Apparent digestibility				
Dry matter (%)	42.6^{c}	53.1^{a}	49.0^{b}	0.8
Gross energy (%)	45.0^{b}	60.0^{a}	48.3^{b}	1.2
Cell walls (%)	40.2^{b}	50.2^{a}	47.4^{a}	1.2
Acid detergent fibre (%)	36.8^{b}	47.5^{a}	45.7^{a}	1.3
Nitrogen (%)	49.6^{ab}	62.1^{a}	56.3^{b}	2.3

a-c Superscripts in the same row indicate values that are not significantly ($P < 0.05$) different when the same letter appears.

1 Expressed on a moisture-free basis.

the digestibility of the P diet was the lowest, the C diet was intermediate and the G diet was the highest. The digestibility of acid detergent fibre was slightly lower in all cases than the calculated digestibility of cell walls; the difference being 2.6%. The values for the G diet must be considered with reservations, however, since in the subsequent digestibility trial involving protein levels, this diet had digestibility coefficients similar to the P diet of this trial (Table 12). A different time period and different animals were, however, involved.

The protein level of the diet had no significant effect on the apparent digestibilities of dry matter, gross energy, cell walls or acid detergent fibre (Table 12). The mean nitrogen apparent digestibilities of 23.6, 38.1 and 58.9% for the LP, MP and HP diets, respectively, were highly significantly ($P < 0.01$) different from one another. In this study the digestibility of the acid detergent fibre fraction was 5.8% less than that calculated for the cell walls.

3.2.4. Effects of Protein Source and Level of Diets

The mean daily feed, energy and protein intakes of the soybean meal (Soy) and BBGU supplemented diets were not significantly different from one another (Table 13). Similarly, no feed and energy intake differences were found due to dietary nitrogen level while crude protein intake increased ($P < 0.01$) with protein content of the diet (Table 13).

There were no significant effects of dietary

TABLE 12. Means and standard errors of dry matter, gross energy and crude protein intake, and apparent digestibilities for sheep fed low, medium and high protein diets[1]

	Low	Medium	High	Standard error
Daily intake				
Dry matter (g)	504^{a}	504^{a}	491^{a}	20
Gross energy (Mcal)	2.15^{a}	2.19^{a}	2.10^{a}	0.09
Crude protein (g)	26.7^{c}	32.8^{b}	47.6^{a}	1.5
Apparent digestibility				
Dry matter (%)	42.4^{a}	42.7^{a}	43.9^{a}	1.7
Gross energy (%)	40.4^{a}	39.6^{a}	43.0^{a}	1.8
Cell walls (%)	41.2^{a}	41.2^{a}	41.6^{a}	1.8
Acid detergent fibre (%)	35.6^{a}	34.9^{a}	36.0^{a}	1.9
Nitrogen (%)	23.6^{c}	38.1^{b}	58.9^{a}	1.7

[a-c] Superscripts in the same row indicate values that are not significantly ($P < 0.05$) different when the same letter appears.

[1] Expressed on a moisture-free basis.

TABLE 13. Means and standard errors of feed, energy and protein intake on an as fed basis for cows fed straw-based diets containing soybean meal or barley based N-glucosyl ureide as a protein supplement

	Protein source			Protein level			
	Soy	BBGU	Standard error	Low	Medium	High	Standard error
Daily feed intake (kg)	9.3^{a}	10.1^{a}	0.4	9.5^{a}	10.0^{a}	9.7^{a}	0.5
Daily feed intake (g/kg weight$^{0.75}$)	84^{a}	91^{a}	3	86^{a}	89^{a}	87^{a}	3
Daily digestible energy intake (Mcal)	17.7^{a}	19.2^{a}	0.7	17.7^{a}	18.6^{a}	19.1^{a}	0.9
Daily crude protein intake (kg)	0.66^{a}	0.70^{a}	0.03	0.50^{b}	0.63^{b}	0.91^{a}	0.03

$^{a-b}$ Superscripts in the same row of each section indicate values that are not significantly ($P < 0.05$ different when the same letter appears.

protein source or level on the change in rumen fill at either the start or the completion of the feeding trial (Table 14). The mean change in fill was 31 and 20 kg at the start and completion of the test, respectively.

Weight gains during the feeding trial were 16 and 9 kg for the Soy and BBGU supplemented diets, respectively (Table 14). The mean weight gains were 9, 11 and 18 kg for the low, medium and high protein diets, respectively, during the 84 day feeding period.

Calf birth weights and weight change of the cows from the beginning of the trial to post-calving were not affected by protein source or level (Table 14).

There were no significant differences in subcutaneous fat depths of cows due to either dietary supplemental protein source or level for either the initial or the final measurement (Table 15). There was a slight loss in fat depth throughout the feeding period, as evidenced by the 4.3 and 3.9 mm mean fat depths at the start and end of the study, respectively.

The levels of plasma free fatty acids were not affected by protein source or level (Table 15). The levels of plasma urea nitrogen appeared somewhat, although not significantly higher, for the Soy diets at 25.3 mg/100 ml of plasma than for the BBGU diets at 22.8 (Table 15). Highly significant ($P < 0.01$) differences due to protein levels were found (Table 15). The mean values for plasma urea nitrogen concentrations for the low, medium and high protein

TABLE 14. Means and standard errors of weights, weight changes, changes in gastro-intestinal fill of cows and birth weights of calves resulting from straw-based diets containing soybean meal or barley based N-glucosyl ureide being fed to cows

	Protein source			Protein level			
	Soy	BBGU	Standard error	Low	Medium	High	Standard error
Initial weight (kg)	521[a]	531[a]	14	528[a]	528[a]	523[a]	17
Weight change[1] (kg)	16[a]	9[a]	6	9[a]	11[a]	18[a]	7
Increase in gastro-intestinal fill at start of test (kg)	30[a]	32[a]	2	30[a]	32[a]	31[a]	2
Decrease in gastro-intestinal fill at end of test (kg)	19[a]	20[a]	3	15[a]	21[a]	23[a]	3
Weight loss from December 6 to post-calving (kg)	45[a]	42[a]	9	36[a]	49[a]	45[a]	11
Calf birth weight (kg)	39[a]	40[a]	2	38[a]	41[a]	39[a]	2

[a] Superscript in the same row of each section indicates values that are not significantly ($P < 0.05$) different.

[1] For the 84 day period from December 20 to March 14. This does not include the first 14 days of the straw feeding period.

TABLE 15. Means and standard errors of fat depths, fat depth changes, plasma free fatty acid and urea nitrogen concentrations of cows fed straw-based diets supplemented with either soybean meal or barley based N-glucosyl ureide

	Protein source			Protein level			
	Soy	BBGU	Standard error	Low	Medium	High	Standard error
Initial fat depth (mm)	4.2^{a}	4.3^{a}	0.6	4.3^{a}	4.9^{a}	3.4^{a}	0.8
Final fat depth (mm)	3.8^{a}	4.0^{a}	0.5	3.7^{a}	5.0^{a}	3.0^{a}	0.6
Fat depth change (mm)	-0.4^{a}	-0.3^{a}	0.3	-0.6^{a}	$+0.1^{a}$	-0.4^{a}	0.4
Plasma free fatty acids (µ moles/ml plasma)	0.80^{a}	0.67^{a}	0.11	0.63^{a}	0.80^{a}	0.78^{a}	0.14
Plasma urea nitrogen (mg/100 ml plasma)	25.3^{a}	22.8^{a}	1.5	13.3^{c}	19.6^{b}	39.3^{a}	1.9

$^{a-c}$ Superscripts in the same row in each section indicate values that are not significantly ($P < 0.05$) different when the same letter appears.

diets were 13.3, 19.6 and 39.3 mg/100 ml of plasma, respectively.

3.2.5. Effects of Straw Level of Diets

The mean daily feed consumption was 12.6, 11.6 and 9.7 kg, or 108, 102 and 86 g/kg weight$^{0.75}$ for the low straw (LS), medium straw (MS) and high straw (HS) diets, respectively (Table 16). The latter of these two results approached a significant difference ($P < 0.10$). Similarly, there were no major differences in straw intake by the cows on different diets (Table 16). However, the daily intake of digestible energy decreased ($P < 0.05$) as the level of straw in the diet increased (Table 16). No significant differences in dietary protein intake were observed.

Mean increases in gastro-intestinal fill, at the start of the test, tended ($P < 0.10$) to decrease as the straw level in the diet increased (Table 17). There were no significant differences among treatments for decrease in fill at the end of the test.

The mean average weight changes during the 84 day feeding trial of 46, 61 and 50 kg for the LS, MS and HS diets, respectively, approached significance ($P < 0.10$) (Table 17). However since the increase in gastro-intestinal fill at the start of test was not uniform and the decreases at the end of test were uniform, the weight change for the 105 day feeding period is the most realistic indication of the effects of the treatments. In the 105 day period, weight gains decreased ($P < 0.01$) as the level of straw in the diet increased.

Calf birth weights were not affected by straw

TABLE 16. Means and standard errors of feed, straw, energy and protein intake on an as fed basis for cows fed diets containing three levels of straw

	Straw level			Standard error
	Low	Medium	High	
Daily feed intake (kg)	12.6[a]	11.6[a]	9.7[a]	0.9
Daily feed intake (g/kg weight$^{0.75}$)	108[a]	102[a]	86[a]	6
Daily straw intake (kg)	9.8[a]	10.0[a]	9.1[a]	0.3
Daily straw intake (g/kg weight$^{0.75}$)	83[a]	87[a]	81[a]	2
Daily digestible energy intake (Mcal)	24.5[a]	21.3[ab]	16.5[b]	1.6
Daily crude protein intake (kg)	0.83[a]	0.69[a]	0.69[a]	0.06

[a-b] Superscripts in the same row indicate values that are not significantly ($P < 0.05$) different when the same letter appears.

TABLE 17. Means and standard errors of weights, weight changes, changes in gastro-intestinal fill of cows and birth weights of calves resulting from diets containing three levels of straw being fed to cows

	Straw level			Standard error
	Low	Medium	High	
Initial weight (kg)	551^{a}	517^{a}	508^{a}	32
Weight change[1] (kg)	46^{a}	61^{a}	50^{a}	5
Weight change[2] (kg)	68^{a}	57^{a}	29^{b}	6
Increase in gastro-intestinal fill at start of test (kg)	39^{a}	24^{a}	7^{a}	9
Decrease in gastro-intestinal fill at end of test (kg)	16^{a}	28^{a}	20^{a}	5
Weight change from December 6 to post-calving (kg)	$+ 14^{a}$	$- 9^{a}$	$- 40^{b}$	8
Calf birth weight (kg)	41^{a}	39^{a}	36^{a}	2

[a-b] Superscripts in the same row indicate values that are not significantly ($P < 0.05$) different when the same letter appears.

[1] For the 84 day period from December 20 to March 14. This does not include the first 14 days of the straw feeding period.

[2] For the 105 day period from December 6 to March 21.

level (Table 17). The mean weight changes to post-calving of 14, - 9 and - 40 kg for the LS, MS and HS diets, respectively, were highly significantly ($P < 0.01$) different from one another.

The initial and final fat depths of the cows were not affected by the treatments (Table 18), although the final fat depths tended ($P < 0.10$) to be higher for the cows which were fed lower levels of straw. There were highly significant ($P < 0.01$) differences in the changes in fat depths, and mean changes for the LS, MS and HS diets were 4.2, 0.2 and - 1.4 mm, respectively.

The plasma free fatty acid mean concentrations were 0.38, 0.31 and 0.92 μ moles/ml of plasma for the cows fed LS, MS and HS diets, respectively (Table 18). These differences approached significance ($P < 0.10$). The mean levels of plasma urea nitrogen for the LS, MS and HS diets were 20.0, 16.6 and 22.3 mg/100 ml of plasma, respectively (Table 18). Differences among diets were significant ($P < 0.05$).

3.2.6. Effects of Concentrate or Hay Supplementation of Diets

There were significant ($P < 0.05$) differences in feed and protein intake and highly significant ($P < 0.01$) differences in feed intake on a metabolic basis between the concentrate and the hay supplemented diets (Table 19). In each instance the concentrate supplemented cows consumed more.

The changes in gastro-intestinal fill at both the

TABLE 18. Means and standard errors of fat depths, fat depth changes, plasma free fatty acid and urea nitrogen concentrations of cows fed diets containing three levels of straw

	Straw level			Standard error
	Low	Medium	High	
Initial fat depth (mm)	4.0^{a}	4.0^{a}	6.0^{a}	1.2
Final fat depth (mm)	8.2^{a}	4.2^{a}	4.6^{a}	1.2
Fat depth change (mm)	$+ 4.2^{a}$	$+ 0.2^{b}$	$- 1.4^{b}$	0.7
Plasma free fatty acids (μ moles/ml plasma)	0.38^{a}	0.31^{a}	0.92^{a}	0.18
Plasma urea nitrogen (mg/100 ml plasma)	20.0^{a}	16.6^{a}	22.3^{a}	1.4

[a-b] Superscripts in the same row indicate values that are not significantly ($P < 0.05$) different when the same letter appears.

TABLE 19. Means and standard errors of feed and protein intake on an as fed basis for cows fed straw-based diets supplemented with concentrate or hay

	Concentrate	Hay	Standard error
Daily feed intake (kg)	11.6^{a}	8.2^{b}	0.8
Daily feed intake (g/kg weight$^{0.75}$)	102^{a}	73^{b}	4
Daily crude protein intake (kg)	0.69^{a}	0.48^{b}	0.05

[a-b] Superscripts in the same row indicate values that are not significantly ($P < 0.05$) different when the same letter appears.

start and end of the test appeared to be greater for the concentrate supplemented diet than for the hay supplemented diet (Table 20). The differences, however, were not significant.

No differences in weights of cows by treatment existed at the start of the test (Table 20). The mean weight gains during the 84 day feeding period were 61 and 25 kg for the concentrate and hay supplemented diets, respectively. These differences were significant ($P < 0.05$).

There were no significant differences in calf birth weights (Table 20). The mean weight changes of the cows from the start of test to post-calving were - 8 and - 66 kg, for the concentrate and hay supplemented diets, respectively.

No significant differences were found in the initial, final or change of fat depth of the cows (Table 21).

The plasma free fatty acid levels of the concentrate supplemented cows were significantly ($P < 0.05$) lower than those of the hay supplemented cows (Table 21), while no differences were found in the levels of plasma urea nitrogen.

3.2.7. Relationship Between Plasma Free Fatty Acid Concentrations and Weight Changes or Days to Calving

Plasma free fatty acid concentrations were correlated with cow weight changes and days to calving (Table 22). The highly significant relationship, between plasma free fatty acid level (Y) and weight change from start of test to post-calving (X), was given by the regression

TABLE 20. Means and standard errors of weight, weight changes, changes in gastro-intestinal fill of cows and birth weights of calves resulting from straw-based diets supplemented with concentrate or hay being fed to cows

	Concentrate	Hay	Standard error
Initial weight (kg)	517^{a}	504^{a}	44
Weight change[1] (kg)	61^{a}	25^{b}	8
Increase in gastro-intestinal fill at start of test (kg)	24^{a}	9^{a}	7
Decrease in gastro-intestinal fill at end of test (kg)	28^{a}	14^{a}	5
Weight loss from December 6 to post-calving (kg)	8^{a}	66^{b}	12
Calf birth weight (kg)	40^{a}	44^{a}	2

[a-b] Superscripts in the same row indicate values that are not significantly ($P < 0.05$) different when the same letter appears.

[1] For the 84 day period from December 20 to March 14. This does not include the first 14 days of the straw feeding period.

TABLE 21. Means and standard errors of fat depths, fat depth changes, plasma free fatty acid and urea nitrogen concentrations of cows fed straw-based diets supplemented with concentrate or hay

	Concentrate	Hay	Standard error
Initial fat depth (mm)	4.0^{a}	2.9^{a}	0.6
Final fat depth (mm)	4.2^{a}	4.8^{a}	0.8
Fat depth change (mm)	$+ 0.2^{a}$	$+ 1.9^{a}$	0.5
Plasma free fatty acids (µ moles/ml plasma)	0.31^{b}	0.85^{a}	0.10
Plasma urea nitrogen (mg/100 ml plasma)	16.6^{a}	18.5^{a}	1.3

[a-b] Superscripts in the same row indicate values that are not significantly ($P < 0.05$) different when the same letter appears.

TABLE 22. Correlation of cow weight changes and days to calving with plasma free fatty acids

Variable	Simple correlation coefficient
Weight change during the feeding period	- 0.33
Weight change from start of test to post-calving	- 0.46
Days to calving	- 0.02

equation: $Y = 0.49 - 0.006X$, where free fatty acid levels were measured in μ moles/ml of plasma and weight changes in kg.

3.3. DISCUSSION

3.3.1. General

Johnson (1972) found that feeding cows high levels of straw could result in problems with abomasal impaction. While most of the cows in this study showed some signs of rumen distension, no major problems with abomasal impactions were encountered. Neither of the two cows lost in the study died of abomasal impaction according to autopsy reports. The cause of death in both cases was related to circulatory failure, with the possibility that rumen distension was involved in the second death. No problems with abomasal impaction were encountered in previous studies with cows in Alberta (Mathison, 1974a, 1974b). The discrepancy in the appearance of impactions between Johnson's (1972) work and these results may have been due to the fact that the straw used was in the long form, whereas chopped, ground and pelleted straw was used in the present study.

The mean daily consumption of digestible energy of all the cows in this study was 18.0 Mcal. This level of intake was about 10% above the NRC (1970) estimate of the energy needs for maintenance of cows of this size. The level of energy intake in this study was about the same as the maintenance estimate found by Dietz (1971) for cows fed under almost identical environmental conditions as the cows in this trial. The mean weight gain of 25 kg

for the cows in the present study suggests that the level of feeding was somewhat above maintenance. This could be due to the combined effects of a decreased energy cost for locomotion (Blaxter, 1967) due to the confined quarters in which the cows were fed and a higher utilization of the energy from the ground and pelleted diets than is suggested by the digestible energy of these feeds (Blaxter and McC. Graham, 1956) as the loss of energy in the form of methane is decreased for ground and pelleted diets relative to chopped diets.

3.3.2. Effects of Physical Form of Diet

There was a positive relationship between feed intake and weight gain on test for cows fed diets in the different physical forms. Since the higher feed intakes of the P diets resulted in larger gains in the cows receiving P diets, it is obvious that the decrease in net energy available for maintenance per unit of the P diets was less than the increase in voluntary intake. Cows fed P diets ate 15% more feed daily than those fed the C diets, whereas the measured difference in digestibility was 7%. The cows fed pellets would be expected to produce less methane per unit of dry matter consumed and to use energy more efficiently for maintenance (Blaxter and McC. Graham, 1956).

The weekly feed intake of the cows receiving P diets was found to be quite variable compared with the other diets. No explanation can be given for this result, except for the possibility that the variations in feed consumption were a manifestation of problems in regulating

the energy balance of these cows (Baumgardt, 1969). Also the cows receiving pellets could vary feed intake more than those receiving the other diets in response to changes in environmental temperature (MacDonald and Bell, 1958; Wodzicka-Tomaszewska, 1965) and still maintain energy equilibrium. The fact that the feed intake of the low protein pelleted diets was greater than that of the other P diets, and that the digestibility of this diet would, if anything, be expected to be lower (Coombe and Tribe, 1963; Lyons et al, 1970; Fishwick et al, 1973) suggested that other factors, in addition to gastro-intestinal fill (Campling, 1969), affected the intake of the cows fed P diets.

In this study the digestibilities of dry matter, gross energy, cell walls, acid detergent fibre and nitrogen were all lower in the P diet than in the C diet. However the digestibilities of the G diet were all higher than those of the C diet. The depression in digestibility of the P diet corresponded with the results in the literature, and is based on the fact that mechanical grinding decreases particle size. Feeding high levels of ground material tends to force the feed through the rumen more quickly, reducing the time feed particles are exposed to rumen micro-organisms, and this tends to lower the digestibility of the feed (Pigden and Heaney, 1969).

The digestibility of the G diet was expected to be similar to that of the P diet (Cloete and Rossouw, 1970) or slightly higher (Levy et al, 1972). In this study the

digestibility of the G diet was unexplainable high, since the same diet fed in the protein level metabolism trial had digestibilities which were about equal to those of the P diet in this study. It was unlikely, however, that an error occurred in the determination of dry matter digestibility of the G diet, as the digestibilities for all sheep in this group were uniformly high.

There is little doubt that the intake of straw can be increased by pelleting or grinding. Pelleted straw diets, in particular, are consumed in greater amounts than chopped straw. There is no doubt, however, that ground or pelleted diets are not feasible for winter maintenance diets for beef cattle. They are expensive to prepare, both in terms of cash and energy inputs. The variability in intake which occurred with the pelleted diets was considered a serious drawback to their use. This may, however, have been corrected if the cows had access to a small amount of long roughage.

3.3.3. Effects of Dietary Protein Level

The significant differences in weight gains due to dietary protein level during the test period cannot be explained by the data obtained. Indeed, the cows fed the LP diet consumed the most feed daily and had the lowest weight gains, even though no significant differences in energy digestibility were measured among the diets.

It was somewhat surprising that no differences in dry matter, energy, cell wall or acid detergent fibre digestibility due to dietary protein concentration were

observed in sheep. This was in contrast with results reported by Coombe and Tribe (1963), Lyons et al (1970) and Fishwick et al (1973) which suggested that dry matter and energy digestibilities of diets improve as protein level increases to the 7 or 8%, following which further increases are not obtained in mature ruminants. The 5.4% crude protein level of the LP diet was sufficient to optimize dry matter digestibility in this trial. The feeding level, one-half maintenance, might have reduced the protein required for optimum dry matter digestibility. Sheep may behave differently than cattle under short term deficiency situations or short term results may differ from long term effects on digestibility.

All of the diets fed met the requirements of the cows for crude protein as outlined by NRC (1970) in terms of total amount of protein provided even though the LP diets were formulated to contain a lower percentage of crude protein than is recommended by NRC. This was due to a higher consumption of feed than is considered normal in the NRC (1970) recommendations. However, on a digestible protein basis the cows fed the LP diets consumed much below the suggested NRC (1970) level, the cows fed the MP diets received about the recommended level and those on the HP diets received in excess of the recommended levels. No explanation as to the absence of protein deficiency symptoms for the cows on the LP diets can be provided.

On the basis of the cattle feeding trials in this experiment, however, it is apparent that the least cost diet

would be the diet of choice for the winter maintenance feeding period, assuming the cows could afford to lose some weight over the winter to post-calving.

3.3.4. Effects of Supplemental Protein Source

In previous work with steers using high levels of roughages (Mathison et al, 1974) and using high energy and low roughage levels (Martin et al, 1975), the slow release non-protein nitrogen supplement, BBGU, compared favourably with oilseed meal protein supplements.

In this study, while weight gains increased with added nitrogen, the differences were not significant. As a result it was not expected that there would be any differences due to protein source. This was, in fact, what occurred. Groups of cattle fed the two supplements showed no differences for all measurements made during the study. Plasma urea nitrogen levels were similar for cows fed soybean meal and BBGU supplemented diets, suggesting that the nitrogen sources were equally effective in terms of overall nitrogen release. Since blood samples were taken prior to feeding, no assessment of the rapidity of breakdown of the nitrogen sources could be made.

It cannot be concluded on the basis of these results that BBGU was an effective protein supplement. However, it can be concluded that BBGU had no detrimental effect on cow performance.

3.3.5. Effects of Dietary Straw Level

The feed intake and the calculated digestible

energy intake of the cows increased as the level of straw in the diet decreased in this study. The uniformity of straw intake as the proportion of straw in the diet increased was in agreement with the findings of other workers, who found no differences in straw intake in maintenance diets when additional concentrate is fed (Bines and Davey, 1970; Mathison, 1974b). The differences in feed and energy intake resulted in decreased weight gains in the HS group. When calculated digestible energy intakes were compared with weight changes it appeared that there was little difference in efficiency of utilization among the diets as weight gains increased as digestible energy intakes increased. This indicates that, in contrast to the results of Slyter et al (1971b), crude fibre digestibility was not substantially reduced by the addition of a starch source to the diet.

3.3.6. Effects of Supplementing with Concentrate or Hay

This trial was designed to evaluate the effect of cellulose as a supplement to straw instead of starch. It was expected that the cellulose in the straw would be digested at a faster rate with hay as a supplement and that the cellulose digestibility would be higher since the depressing effect of starch on cellolytic bacteria would be decreased (Slyter et al, 1971a). No evidence was obtained in this trial to support this concept.

The daily feed intake of the cows receiving the hay supplemented diet was markedly less than that of the concentrate supplemented cows. As a result the concentrate

supplemented group gained more weight over the winter. This occurred in spite of the fact that the crude protein content of the two diets was similar and the acid detergent fibre content of the hay supplemented diet was only slightly higher than that of the concentrate supplemented diet. The low intake of the hay supplemented diet might, however, have been caused by the dustiness of the diet since the pellets did not bind together well, so that the resulting feed consisted of fragments of pellets and dust particles.

As a result of the differences in feed intake no conclusion on the use of hay versus concentrate as a supplement to straw was possible. The weight gains achieved by the hay supplemented group with a relatively low feed consumption, compared with gains achieved by the cows in other sections of this study, indicated the possibility of better utilization of hay supplemented diets compared with concentrate supplemented diets.

3.3.7. Ultrasonic Measurement of Fat Cover as an Indicator of Nutritional Status

The change in depth of subcutaneous fat has been used as an indicator of nutritional status in beef cows (Dietz, 1971). In that study, a loss in subcutaneous fat was considered an indication that fat was mobilized to meet the energy requirements of cows. On an overall basis, the cows in the present study showed virtually no change in mean fat depth, while there was a moderate, overall net gain in body weight. There were, however, wide positive and

negative fluctuations in fat depth change for individual cows. Similar variations have been found by Dietz (1971) and Johnson (1972). Since the cows were not slaughtered, it was not possible to make actual carcass measurements. It was, therefore, not possible to determine if the fat depth changes measured had occurred or if the differences were the result of misinterpretation of the ultrasonic scans (Miles et al, 1972). However, since the fat depths measured were less than those ultrasonic equipment is normally used for, it was felt that the latter was the case. For thin cows, body weight changes are probably a better indicator of change in nutritional status than ultrasonic fat depth measurements.

3.3.8. Plasma Free Fatty Acids as Indicators of Nutritional Status

Plasma free fatty acid concentrations can be increased by undernourishment during pregnancy (Bowden, 1974), late pregnancy alone (Robinson et al, 1971) or undernourishment alone (Owen et al, 1969c). Regression analysis showed that plasma free fatty acid levels were most affected by weight change. The increases in free fatty acid level due to pregnancy normally begin in the period 31 to 60 days prepartum (Bowden, 1974). Since the average number of days before calving in this study at time of sampling was 59 days and no cows were less than 37 days prepartum, it was deemed reasonable the free fatty acid levels were more closely related to weight changes than stage of pregnancy. The levels

of plasma free fatty acids measured were about the same as those obtained by Bowden (1974), but were lower than those of Dietz (1971).

3.3.9. Plasma Urea Nitrogen as an Indicator of Protein Intake

Plasma urea nitrogen levels in sheep are closely related to protein intake (Torrel et al, 1974). The increases in plasma urea nitrogen concentrations as protein intake increased in this study indicated that this relationship could be used as an assessment of the nitrogen intake of cattle.

4. EXPERIMENT II. STRAW IN PRODUCTION DIETS

Several workers have studied the effects of straw fed at relatively low levels in feedlot diets of steers. Information about the effects of feeding very high levels of straw in feedlot diets is very limited. Some research has been carried out in Great Britain (Swan and Lamming, 1970) but no work has been performed under Western Canadian conditions for straw levels exceeding 40%. The performance of beef steers fed completely pelleted diets containing three levels (up to 70%) of barley straw was assessed in the present study.

4.1. MATERIALS AND METHODS

4.1.1. Design of the Experiment

The experiment included 18 steers, of British breeds and crosses, in a three by three by two nested factorial design. Three levels of straw, in isonitrogenous pelleted diets, were compared with respect to their effect on efficiency of feed utilization, growth rate and carcass characteristics of the steers. Each of the three pens used in the experiment housed six steers, so that two steers in each pen were fed the same diet.

4.1.2. Experimental Site and Facilities

The experiment was conducted at the University of Alberta, Beef Cattle Nutrition Unit at the Ellerslie Research Station. The steers were kept in three pens of one shed at

the facility. Each pen, which accommodated six steers, measured about 4.0 by 7.6 m. Wind and overhead shelter was provided by the barn. Water was provided from heated watering bowls connected to the underground water system.

Each pen was equipped with six stanchions which were used to confine the steers individually during the feeding periods. The concrete feed bunk in front of each pen was divided into six sections to allow for individual feeding of the animals.

The scale for weighing the steers and the cattle squeeze for restraining the animals during any medical treatment required were located in a separate building adjacent to the feeding sheds.

4.1.3. Animals and their Management

The 18 steers used in the trial were selected for uniformity of weight from a group of 54 steers which had been purchased through commercial channels. No information regarding the history of the animals was available. The breed composition was obviously mainly Herefords, with some Hereford-Angus and Hereford-Shorthorn crosses. The steers were assigned to treatment groups on the basis of their weights on December 10, 1974, so that the average weight of the steers in each treatment group was as close as possible to the overall mean. The live-weights of the steers ranged from 287 to 340 kg, with a mean of 304 kg at the start of the test.

A 2 ml dose containing 1,000,000 IU of Vitamin A, 150,000 IU of Vitamin D and 1,000 IU of Vitamin E, was injected intramuscularly into each steer on December 16, 1974. Each steer was also vaccinated against blackleg and malignant edema that day. The steers were implanted with a growth promoting hormone, Ralgro (Commercial Solvent Ltd., Terpe Haute, Indiana), on December 17, 1974. May 7, 1975 was the date of treatment for warbles with the pour-on insecticide, Ruelene (Dow Chemical Com., Midland, Michigan).

From December 16, 1974 until May 28, 1975 the steers were managed similarly. Each steer, however, was offered its daily diet while confined in an individual stanchion and was allowed about 2 to 3 hours each morning and afternoon (between 0800 and 1130 hours and between 1330 and 1630 hours) to consume its feed. Water was available *ad libitum* except during the time of confinement for feeding and prior to weighing. The animals were slaughtered May 28, 1975.

4.1.4. Diets

The diets used in this study were prepared as complete pelleted diets. The straw and concentrates were ground through a 4.8 mm screen and then pelleted into 6.4 mm diameter pellets. Details of the diet are given in Table 23.

TABLE 23. Formulation and composition of steer diets

Feedstuff[1]	Straw level		
	Low	Medium	High
Barley straw	40.0	55.0	70.0
Barley	54.0	35.5	16.9
Rapeseed meal	4.7	8.3	12.0
Calcium-phosphate (18:20.5)	0.10	0.21	0.25
Limestone	0.50	0.30	0.15
Trace mineral salt	0.50	0.50	0.50
Vitamin premix[2]	0.22	0.22	0.22
Total	100.02	100.02	100.02
Analyzed composition (moisture-free basis)			
Dry matter (%)	92.0	92.8	93.1
Acid detergent fibre (%)	23.5	30.3	39.2
Crude protein (%)	9.8	9.9	9.7
Calcium (%)	0.54	0.60	0.59
Phosphorus (%)	0.39	0.39	0.32

[1] Expressed as % in total diet on a moisture-free basis.

[2] Each kg of premix contained 2,000,000, 350,000 and 2,000 IU of Vitamin A, D and E respectively.

Three composite samples were collected for each of the diets in the experiment for the determination of each diet's composition. Each composite sample was composed of a mixture of three samples taken on three different days, so that the average composition presented is the result of sampling at nine different times.

4.1.5. Digestibility Trial

A digestibility trial was performed for each diet using 12 Suffolk wethers, individually housed in metabolism cages. Four sheep received each of the three diets tested in a three by four nested factorial design. The experimental animals received the test diets once daily in the morning. The sheep were allowed 7 days to become accustomed to the diets offered. The level of feeding was then adjusted using the formula presented by NRC (1968) to provide the digestible energy required for the maintenance of each sheep. The sheep were fed at this level for 14 days.

During the last 6 days of the trial, the total feces produced by each sheep was collected and weighed once daily. Samples, representing a constant proportion of the daily fecal output of the individual sheep, were dried in a force-draft oven at 55 C for 72 hours. Then the six samples for each sheep were combined to produce one composite sample for each sheep. The samples were finely ground using a Christy-Norris grinding mill and were stored in plastic containers.

4.1.6. Measurements

The steers were fed at a level twice daily such that on most days some of the feed offered remained after the feeding period. Daily feed consumption was calculated from this information. Digestible energy and digestible crude protein intakes were calculated using the daily feed intake and the digestibilities determined in the digestibility trial.

During the experiment the steers were weighed at weekly intervals. In addition, they were weighed on two consecutive days at both the start and the completion of the feeding trial. The weights were taken in the morning before feeding and after the steers had been kept away from water for approximately 16 hours.

The warm dressed weight of each animal was taken on the federally approved scale at the packing plant. The day following slaughter the average fat cover, the area, marbling and colour of the rib eye and the quality grade of each carcass were determined by Agriculture Canada meat graders.

Gross energy of feed and fecal samples was determined by means of a Parr oxygen bomb calorimeter. Cell wall content was determined by the method of Goering and Van Soest (1970) as modified (Appendix I). Samples were analyzed for dry matter, acid detergent fibre and crude protein by the Alberta Soil and Feed Testing Laboratory. Dry matter was determined by the AOAC (1965) method. The method of Goering and Van Soest

(1970) was used in the determination of acid detergent fibre. Crude protein (N x 6.25) was determined by Technicon Methodology No. 218-72A.

4.1.7. Statistical Analysis

Analysis of variance was performed using computer programs available from the University of Alberta Computing Centre. Duncan's New Multiple Range Test (Steel and Torrie, 1960) was used in comparison of means.

4.2. RESULTS

4.2.1. General

All the steers remained healthy throughout the experiment. Occasionally an animal did not eat for one or two feedings. This normally occurred after a period of abnormally high feed intake. Animals that went off feed were normally back to normal consumption two or three feedings after they began to eat again.

At slaughter, the livers of all the steers were inspected for abscesses. Only one animal of the 18 slaughtered had an abscessed liver. This was from an animal in the low straw (LS) treatment group.

4.2.2. Digestibility of Diets

There was a highly significant ($P < 0.01$) reduction in apparent dry matter digestibility as the level of straw in the diet increased (Table 24). Similar reductions ($P < 0.01$) in digestibility of gross energy were found. There were no significant differences in the digestibility of cell walls, acid detergent fibre or nitrogen among the diets.

4.2.3. Feed, Energy and Protein Intake and Feed Conversion

There were no significant differences in feed intake among the treatment groups, although the feed intake of the medium straw (MS) group appeared somewhat lower than that of the other two groups (Table 25). The LS group consumed significantly ($P < 0.05$) more digestible energy

TABLE 24. Means and standard errors of dry matter, gross energy and crude protein intake, and of apparent digestibilities of diets containing 40, 55 and 70% barley straw fed to sheep

	% Straw			Standard error
	40	55	70	
Daily intake				
Dry matter (g)	741^{b}	831^{ab}	932^{a}	34
Gross energy (Mcal)	3.20^{b}	3.49^{ab}	3.92^{a}	0.14
Crude protein (g)	72^{a}	78^{a}	83^{a}	3
Apparent digestibility				
Dry matter (%)	61.1^{a}	52.7^{b}	49.1^{b}	2.0
Gross energy (%)	61.1^{a}	53.4^{b}	48.7^{b}	2.1
Cell walls (%)	36.8^{a}	32.7^{a}	37.0^{a}	3.0
Acid detergent fibre (%)	27.9^{a}	34.6^{a}	33.4^{a}	3.0
Nitrogen (%)	49.6^{a}	52.5^{a}	52.6^{a}	1.7

[a-b] Superscripts in the same row indicate values that are not significantly ($P < 0.05$) different when the same letter appears.

TABLE 25. Means and standard errors of feed, energy and protein intake, feed, concentrate and energy conversion, and weight and gain of steers fed diets containing 40, 55 and 70% barley straw[1]

	% Straw			Standard error
	40	55	70	
Daily feed intake (kg)	8.9^{a}	8.4^{a}	9.0^{a}	0.1
Daily digestible energy intake (Mcal)	21.6^{a}	17.5^{b}	18.6^{b}	0.3
Daily crude protein intake (kg)	0.80^{a}	0.77^{a}	0.81^{a}	0.01
Daily digestible crude protein intake (kg)	0.40^{a}	0.40^{a}	0.43^{a}	0.01
Feed/gain (kg/kg)	10.9^{b}	12.0^{b}	14.1^{a}	0.5
Concentrate/gain (kg/kg)	6.5^{a}	5.4^{b}	4.2^{c}	0.3
Digestible energy/gain (Mcal/kg)	26.4^{a}	25.0^{a}	27.0^{a}	1.2
Initial weight (kg)	303^{a}	305^{a}	305^{a}	7
Average daily gain (kg)	0.82^{a}	0.71^{ab}	0.66^{b}	0.04

a-c Superscripts in the same row indicate values that are not significantly ($P < 0.05$) different when the same letter appears.

1 Expressed on an as fed basis.

than the other groups. No differences were found in protein consumption.

The kg of feed required per kg of gain increased as the amount of straw in the diet increased ($P < 0.05$). There were highly significant ($P < 0.01$) decreases in the kg of concentrate required per kg of gain as straw level increased. No significant differences in digestible energy required per kg of gain were found.

4.2.4. Weights and Weight Gains

No significant differences for either mean initial or mean final weights were obtained among the three treatment groups (Table 25). The average daily gains of the steers tended ($P < 0.10$) to be reduced as the level of straw in the diet increased. With the exception of a gradual trend towards greater gain for the LS group, the growth pattern of the three groups was similar.

4.2.5. Carcass Data

The differences in warm carcass weight of the steers at slaughter by treatments were highly significant ($P < 0.01$) (Table 26). Carcass weights decreased with increasing straw in the diet. The mean dressing percentages by group ranging from 50.4 to 53.7 showed no significant differences, although the dressing percentage appeared to decrease as the amount of straw in the diet increased.

There were no differences in rib eye area between the 11th and 12th ribs among the treatment groups. The mean fat cover and the amount of marbling both decreased signif-

TABLE 26. Means and standard errors of carcass characteristics of steers fed diets containing 40, 55 and 70% barley straw

	% Straw			Standard error
	40	55	70	
Carcass weight (kg)	227^{a}	215^{b}	204^{b}	4
Dressing percentage	53.7^{a}	52.4^{a}	50.4^{a}	1.0
Area of rib eye (cm^2)	53.3^{a}	54.7^{a}	52.4^{a}	2.1
Fat cover (mm)	8.8^{a}	5.1^{b}	5.5^{b}	0.8
Marbling[1]	7.0^{b}	8.0^{a}	8.2^{a}	0.3
Colour[2]	1.2^{a}	1.3^{a}	1.7^{a}	0.2
Grade[3]	1.2^{a}	1.8^{a}	2.3^{a}	0.2

a-b Superscripts in the same row indicate values that are not significantly ($P < 0.05$) different when the same letter appears.

1 Marbling score is based on USDA system where the numbers 1 to 9 are used to designate extreme and no marbling respectively.

2 Bright red colour = 1, medium dark red colour = 2.

3 Canada grade A1 = 1, B1 = 2 and C1 = 3.

icantly ($P < 0.05$) as the straw level in the diet increased

Although there were no significant differences by the method of analysis in the colour of the rib eye, four carcasses in the high straw (HS) group, and two in the MS group showed a medium red colour when graded as compared with only one in the LS group.

The distribution of grades of the carcasses was five A1 and one B1 carcasses in the LS group, one A1 and five B1 carcasses in the MS group, and one A1, three B1 and two C1 carcasses in the HS group. In each case the minimum fat cover was a determining factor in reducing the grade. The carcasses with a lesser fat cover also tended to have less marbling and a darker colour of the rib eye. However, by the method of analysis used only a trend ($P < 0.10$) towards reduced grade with increased straw in the diet was indicated.

4.3. DISCUSSION

4.3.1. Digestibility of Diets

As the acid detergent fibre and cell wall content of the diets increased, the digestibilities of dry matter and gross energy decreased. The results were in agreement with the lower digestibility of cell walls relative to cellular contents reported by Van Soest (1967). The calculated digestibilities of gross energy, assuming no straw-concentrate interaction and NRC (1969) digestibilities of the feedstuffs, were 68, 63 and 57% compared with the values of 61.1, 53.4 and 48.7% for the LS, MS and HS diets, respectively, which were obtained in this study. This difference can be attributed to the decreased digestibility associated with the use of pelleted diets which has been found by many workers and would indicate limited, if any, associative effects on digestibility among the feedstuffs.

4.3.2. Feeding Efficiency and Weight Gains

The trend toward decreased weight gains as the level of straw in the diet increased combined with slight differences in feed intake resulted in poorer feed conversions with increased straw levels. This was in agreement with the work of other researchers (Nicholson, 1967; Forbes et al, 1969a; Kay et al, 1970a,1970b) at lower percentages of straw in the diet. Swan and Lamming (1970) found similar trends at straw levels comparable with those

fed in the present study, however the average daily gain of the steers in that trial was higher and less feed was required per unit of gain. Swan and Lamming (1970) used Freisian steers fed over the same weight range as the steers in the current trial.

No apparent differences in digestible energy required per unit of gain were found. Similar results were obtained by Forbes et al (1969a) and Swan and Lamming (1970). At lower levels, however, the use of 0 to 40% straw resulted in increases in digestible energy required per unit of gain (Forbes et al, 1969b). Hironaka and Bailey (1968) also found that the amount of digestible energy required per unit of gain decreased as the proportion of barley in a barley-alfalfa diet increased.

There was apparently less energy retained by the steers per unit of weight gained as the level of straw in the diet increased since the steers on the HS diets had the lightest carcasses and the least fat cover.

No leveling off of gains of the steers on the MS and HS diets occurred in this trial. This was in contrast with the results of Swan and Lamming (1970).

4.3.3. Carcass Data

The decreases in live-weight and the slight decreases in dressing percentage resulted in the significant decreases in carcass weight as the amount of straw in the diet increased. The trend towards decreased dressing percentage as the level of straw increased was in agreement

with the work of other researchers (Kay et al, 1970a, 1970b; Swan and Lamming, 1970) who found that decreased dressing percentages were the result of increased alimentary-tract fill. The dressing percentages of these animals was about 5% less than normal in steers of these grades (Berg, L., Agriculture Canada, personal communication).

The amount of lean in the carcasses, as indicated by the area of rib eye, was found not to vary among treatments. This was in agreement with the results of Swan and Lamming (1970). Fat cover and marbling were both found to be increased for the LS diet compared with the MS and HS diets. Again, these results were in agreement with the work of Swan and Lamming (1970). The carcass grades also indicated a lack of finish on the carcasses of the steers fed the MS and HS diets. The LS diet was of sufficiently high energy concentration to produce acceptable carcasses at the weights at slaughter. The animals fed the MS and HS diets might have fattened sufficiently in another month to grade Canada A. However, it was also possible that the growth rate of the animals would decrease as happened in Swan and Lamming's (1970) work. Although there were indications that the darker colour of the rib eye associated with the MS and HS diets was related to the nutritional program, it could not be concluded that the cause was nutritional.

5. EXPERIMENT III. EFFECTS OF WEATHERING ON THE NUTRITIVE VALUE OF STRAW

There is a wide spread belief among producers that cows will voluntarily consume more straw after it has been weathered. The main objectives of this study were thus to examine the effects on nutritive value of exposing barley straw to the outdoor environment.

5.1. MATERIALS AND METHODS

5.1.1. Design of the Experiment

Twelve Suffolk wethers were selected for this experiment and allotted to treatments in which three different samples of barley straw were fed in a three by four nested factorial design.

5.1.2. Animals and their Management

The experiment was conducted at the Metabolic Unit at the University Farm in Edmonton. The sheep were kept in individual metabolic cages, each equipped with a feed and water trough. The environmental temperature was maintained at 15 to 18 C during the trial. The sheep, with live-weights ranging from 45 to 55 kg, were assigned to treatment groups such that each group averaged 50 kg in weight. They had previously been placed in individual cages and fed a hay diet for 5 days while becoming accustomed to the new surroundings. A 1.5 ml dose, containing 750,000, 112,500 and 750 IU of Vitamin A, D and E, respectively, was

administered intramuscularly to each sheep 2 days after the beginning of the trial.

Each sheep was fed twice daily an amount in excess of voluntary consumption during the first 12 days of the trial to establish its level of voluntary feed intake. For the next 12 days each sheep was offered 85% of the mean amount of the feed it consumed during the last 5 days of the initial period. Total fecal output was collected during the final 6 days of the trial.

5.1.3. Diets

Three experimental diets were used in the study. Two of the diets contained year-old straw which had been stacked in loose piles containing about 2 tonnes each. A visibly weathered portion from the outside of the stack, and a less weathered portion from about 1 m into the stack were selected for the experiment. New straw was similarly obtained for comparative purposes from straw produced the following year in the same field under a similar fertilization program. Visibly, there was little difference between the weathered straws, but there was a large difference between them and the new straw. All the straw had been put through the chopper on the combine, and collected immediately along with the chaff, leaves and grain lost in the combining process. The straw was baled from the stacks to facilitate transportation to the experimental site. It averaged about 10 cm in length at the time of the trial.

Each sheep received 10 g of a calcium-phosphorus

(18% calcium: 20.5% phosphorus) mineral and 10 g of trace mineral salt daily. For the first 12 days of the experiment, each sheep received 150 g of soybean meal plus straw in excess of voluntary consumption. For the final 12 days each sheep was offered a diet consisting of 85% straw and 15% soybean meal at a reduced level.

5.1.4. Measurements

Daily feed consumption was measured for each sheep. During the final 6 days of the trial, total fecal output was collected and weighed once daily. Samples, representing a constant proportion of the daily fecal output of each sheep, were dried in a force-draft oven at 55 C for 72 hours. The six samples for each sheep were combined to make one composite sample for each sheep. Each sample was finely ground using a Christy-Norris grinding mill and was stored in a plastic sample cup.

To calculate the apparent digestibility of the straw in each diet, the amounts of energy and crude protein which were derived from the soybean meal were subtracted from the total amount digested. The digestibilities of gross energy and crude protein in soybean meal were assumed to be those given by NRC (1969).

The feed and fecal samples were analyzed for dry matter by the AOAC (1965) method. Gross energy was determined with a Parr oxygen bomb calorimeter. Cell wall content was measured by the method of Goering and Van Soest (1970) as modified (Appendix I). Acid detergent fibre was determined

by the method of Goering and Van Soest (1970). Technicon Methodology No. 218-72A was used in the analysis of crude protein (N x 6.25).

5.1.5. Statistical Analysis

Analysis of variance was performed using computer programs available from the University of Alberta Computing Centre. Duncan's New Multiple Range Test (Steel and Torrie, 1960) was used in comparison of means.

5.2. RESULTS

5.2.1. General

All the animals remained healthy throughout the trial. Occasionallly during the collection period, some of the sheep fed weathered straw left up to 15% of the straw offered to them. The straw remaining was subtracted from the amount offered that day to obtain feed consumption. The loss of feed by spillage was slight. Each group of sheep lost some body weight during the 24 days of the trial. The average weight loss was 2.7, 4.3 and 3.6 kg for the group fed new straw (NS), weathered straw from the outside of the stack (WSO) and weathered straw from the inside of the stack (WSI), respectively.

5.2.2. Composition of the Straw

Chemical analysis of the straws indicated the there was no major difference in chemical composition between the two types of weathered straw (Table 27). The levels of cell wall content and acid detergent fibre were higher in the weathered straw than in the new straw and the crude protein and phosphorus were lower.

5.2.3. Feed Intake and Fecal Output

The sheep, during the first 12 days of the trial, consumed significantly ($P < 0.05$) more new straw than weathered straw. There was no difference in voluntary intake of the two types of weathered straw (Table 28). The standard error

TABLE 27. Chemical composition of weathered and new straw[1]

	New straw	Weathered straw outside	Weathered straw inside
Gross energy (cal/g)	4360	4338	4286
Cell walls (%)	68.4	83.6	81.5
Acid detergent fibre (%)	38.9	53.2	52.8
Crude protein (%)	6.3	2.9	3.0
Calcium (%)	0.34	0.32	0.34
Phosphorus (%)	0.15	0.10	0.10

[1] Expressed on a moisture-free basis.

TABLE 28. Means and standard errors of intake, apparent and calculated digestibilities of weathered and new straw diets fed to sheep

	New straw	Weathered straw outside	Weathered straw inside	Standard error
Daily voluntary consumption of straw[1] (g)	802^{a}	611^{b}	600^{b}	49
Daily intake during the collection period				
Dry matter (g)	854^{a}	577^{b}	598^{b}	67
Gross energy (Mcal)	3.76^{a}	2.55^{b}	2.64^{b}	0.29
Crude protein (g)	126^{a}	76^{b}	77^{b}	8
Apparent digestibility				
Dry matter (%)	62.8^{a}	50.1^{c}	54.5^{b}	1.0
Gross energy (%)	64.8^{a}	53.1^{c}	57.2^{b}	1.0
Cell walls (%)	57.0^{a}	53.0^{a}	57.0^{a}	1.2
Acid detergent fibre (%)	52.3^{a}	48.3^{b}	54.8^{a}	0.9
Nitrogen (%)	76.0^{a}	70.2^{b}	70.9^{b}	1.0
Calculated digestibility of straw				
Gross energy (%)	62.6^{a}	47.4^{c}	52.2^{b}	1.1
Nitrogen (%)	50.0^{a}	-22.3^{b}	-13.9^{b}	3.1

[a-c] Superscripts in the same row indicate values that are not significantly ($P < 0.05$) different when the same letter appears.

[1] Expressed on a moisture-free basis.

for the voluntary intake reflected the large variability in consumption for individual sheep. The significant differences in the intake of dry matter and straw during the collection period reflected the conditions of the trial, as feed offered in this period was based on the amount consumed in the initial period.

5.2.4. Apparent and Calculated Digestibilities of Diets

The dry matter digestibilities of the diets were 62.8, 50.1 and 54.5% for the NS, WSO and WSI groups, respectively, and this represented highly significant ($P < 0.01$) changes (Table 28). There were no significant differences in cell wall digestibility among the diets, while the digestibility of acid detergent fibre was highly significantly ($P < 0.01$) reduced in the WSO group. Highly significant ($P < 0.01$) differences were found for nitrogen digestibility, with the nitrogen in the NS being more apparently digestible than the nitrogen in the weathered straw. There were highly significant ($P < 0.01$) differences in the digestibility of gross energy among the three types of straw. The calculated values were 62.6, 47.4 and 52.5% for gross energy digestibility, and 50.0, - 22.3 and - 13.9% for nitrogen digestibility in the NS, WSO and WSI groups, respectively.

5.3. DISCUSSION

5.3.1. Composition of the Straw

The interpretation of the results obtained for comparison of the types of straw is influenced by the similarity of the straws at harvest. Unfortunately, no chemical analysis of the year-old straw was performed at the time of harvest so no direct comparisons between the weathered straw and the new straw can be made. The straws tested were all grown in the same field, which had been continuously cropped for several years. The level of fertilization, stage of harvesting and yield of grain were also about the same in both years. The straw was not rained on before stacking either year.

The crude protein content of the new straw was about 50% higher than levels normally reported for barley straw (NRC, 1969). The method of harvesting of the crops which produced the straw samples included the collection of chaff and leaves with the straw, while most straw tested consists primarily of stems, as leaves and chaff are lost from the straw before baling. A large amount of leaves and chaff were evident in all samples used in this study. The increased protein content of leaves and chaff relative to stems (Kilcher and Troelsen, 1973) could explain the crude protein content of the new straw.

Forages subjected to rain between cutting and completion of harvest show increases in acid detergent fibre

levels and decreases in crude protein content (Martin, P.J., Alberta Agriculture, personal communication). A similar trend was suggested for weathered straw by results found in this study. Increased cell wall contents suggested a decrease in cellular contents of the straw (Van Soest, 1969). The decrease in cellular contents were reflected in the decrease in nitrogen in the weathered straw, as this component tends to be concentrated in the cellular contents of straw.

5.3.2. Voluntary Consumption of Diets

For diets with low digestible energy concentrations, rumen fill limits feed intake (Baumbardt, 1969a). Voluntary consumption is limited by the capacity of the reticulorumen and by the rate of disappearance of digesta from the rumen (Campling, 1969). In the present study, the voluntary intake of weathered straw was depressed relative to the new straw. The lower cell wall content of the new straw and the associated improvement in digestibility of gross energy (Van Soest, 1967) may have resulted in higher intake of the new straw. In addition, the presence of small amounts of mould in the weathered straw may have had a depressing effect on voluntary intake (Morrison, 1956). In any case there was no evidence for the common belief of some producers that ruminants will eat more weathered straw than new straw.

5.3.3. Digestibility of Diets

The cellular contents of forages are completely or almost completely nutritionally available to ruminants

while cell walls are less nutritionally available (Van Soest, 1969). These findings were reflected in the results of this study and the increased energy digestibility of the new straw was attributed to the increased content of the more readily available cellular contents in the new straw.

The decreased apparent digestibility of nitrogen in the weathered straw was related to a lower nitrogen content in the weathered straw relative to the new straw. The calculated apparent digestibility of nitrogen in the straw was in close agreement with the formula used to calculate the digestible protein content of feedstuffs (NRC, 1970). This suggests that there was little difference in the true digestibility of the nitrogen in the different types of straw.

The digestibility of acid detergent fibre was lower than that of cell walls. Acid detergent fibre is a measurement of the cellulose and lignin in a feedstuff, while the cell wall includes hemicellulose, cellulose and lignin (Goering and Van Soest, 1970). The reduced digestibility of acid detergent fibre relative to that of cell walls may be attributed to the larger proportion of indigestible lignin in acid detergent fibre.

The difference in digestibility of the new straw compared with the weathered straw resulted despite the fact that the intake of the new straw diet was nearly 50% greater than that of the weathered straw diets. Increased intake has been shown to significantly decrease digestibility of diets Blaxter et al, 1956), so that the differences in digestibility

might have been even greater if daily intakes of all diets had been equalized. There was thus no indication that the digestibility of straw is improved by the weathering process.

6. GENERAL DISCUSSION AND CONCLUSIONS

The levels of straw used in the cow maintenance studies were much higher than those normally used in Western Canada. The high levels of feed and straw intake obtained were similar to those obtained by Mathison (1974a, 1974b) and previously, by British researchers. These levels of straw intake may in part have been attributed to the increased intake which can result when the particle size of the feed is reduced (Agriculture Canada, 1974). Differences due to treatments have been described but on an overall basis the mean weight gain of the cows during the 84 day feeding trial was 25 kg, while the mean loss in weight from start of test to post-calving was 36 kg. All the cows which completed the study were considered to have completed the trial in acceptable body condition. This suggested that the most economical diet would be the diet of choice. However, the effects of nutrition on subsequent performance was not determined. In addition, the loss of two of 60 cows can be considered high. Dietary treatments may have affected these death losses. The climatic conditions during the first two months of the trial were relatively mild, indicating that weight gains may have been decreased if the winter had been colder, as the ability of cows to increase feed intake on these diets was somewhat limited. On a practical basis though, it may be concluded that barley straw can be used

in relatively high amounts in maintenance diets of mature cows if the straw is properly supplemented with energy, protein, mineral and vitamins.

The results of the production trial using steers demonstrated that up to 70% straw could be used in a growing diet. At this level of straw, 4.2 kg of concentrate were required per kg of gain. This amount is less than that normally required in more conventional diets. Processing costs involved in making a complete pelleted diet based on straw are extremely high. In addition straw at high levels resulted in what were considered to be reduced daily gains of the steers relative to those expected with conventional diets. Even if the feed costs per unit gain for the straw-based diets were comparable with normal diets, the reduced daily gains would result in higher total costs for the high straw diets when all overhead costs are considered. In addition, if chopped or ground straw diets were used at similar levels as in this study, a decrease in daily intake and gain along with a poorer feed conversion could result (Agriculture Canada, 1974). Thus it appeared in these studies that straw was used more economically in maintenance diets than in production diets for beef cattle.

Weathered straw was found to be low in nutritive value as determined by analysis, voluntary consumption and digestibility measurements. As a result of the relatively low nutritive value of straw in any case, it is probable that weathered straw should not be used as a feedstuff.

If it must be used, it should be mixed with better quality feedstuffs and used in maintenance diets.

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APPENDIX I

PROCEDURE FOR THE DETERMINATION OF NEUTRAL DETERGENT FIBRE

Reference: Goering, H.K. and P.J. Van Soest. 1970. Forage fibre analyses (apparatus, reagents, procedures, and some applications. U.S.D.A. Agriculture Handbook No. 379, Washington, D.C. p. 5-8.

Reagents and Equipment

1. Neutral-detergent solution

   1 litre distilled water
   30 g. sodium lauryl sulfate
   18.61 g. disodium ethylenediamine tetraacetate (EDTA), dihydrate crystal, reagent grade
   6.81 g. sodium borate decahydrate, reagent grade
   4.56 g. disodium hydrogen phosphate, anhydrous, reagent grade
   10 ml. 2-ethoxyethanol, purified grade

   Put EDTA and $Na_2B_4O_7 \cdot 10H_2O$ together in a large beaker, add some of the distilled water, and heat until dissolved; then add to solution containing sodium lauryl sulfate and 2-ethoxyethanol. Put Na_2HPO_4 in beaker, add some of the distilled water, and heat until dissolved; then add to solution containing other ingredients. Adjust pH to 6.9 to 7.1, if necessary.

2. Decahydronaphthalene or commercial foam depressant.

3. Acetone - a colour-free grade which leaves no residue when evaporated.

4. Soldium sulfite - anhydrous, reagent grade.

5. Refluxing apparatus with beakers, ceramic hot plates and Pyrex glass reflux condensers.

6. Vacuum flasks or a vacuum filter manifold.

7. Gooch crucibles.

Procedure

1. Weigh 0.5 to 1.0 g. air-dry feed or fecal sample ground to pass a 1 mm. mesh into a beaker of the refluxing apparatus.

2. Add in order, 100 ml. of neutral detergent solution at room temperature, 2 ml. decahydronapthalene (or other foam depressant) and 0.5 g. sodium sulfite with a calibrated scoop. Heat to boiling. Reduce heat as boiling begins, to avoid foaming. Adjust boiling to an even level and reflux for 60 minutes from the onset of boiling.

3. Placed previously tared crucibles on vacuum attachment. Swirl beaker to suspend solids, and fill crucible. Do not admit vacuum until after crucible has been filled.

4. Use low vacuum at first and increase force as needed. Rinse sample into crucible with minimum of hot (90°-100°C) water.

5. Remove vacuum, break up mat, and fill crucible with hot water. Filter liquid and repeat washing procedure.

6. Wash twice with acetone in same manner and suck dry.

7. Dry crucibles at 100°C for 8 hours and weigh. Yield of recovered neutral-detergent fibre is reported as per cent of cell wall constituents.

8. Feed samples containing high levels of starch may form a gel which slows filtering and may increase the apparent per cent cell wall constituents.

APPENDIX II

PROCEDURE FOR THE DETERMINATION OF FREE FATTY ACIDS

Reference: Mosinger, F. 1965. Photometric adaptation of Dole's microdetermination of free fatty acids. J. Lipid Res. 6: 157-159.

Reagents and Equipment

1. Extraction Mixture

   40 parts isopropanaol
   10 parts heptane
   1 part 1 N. H_2SO_4

2. Stock Buffer

   0.5% phenol red in 0.12 M. sodium barbital

3. Colour Reagent

   99 ml. absolute ethanol
   200 ml. heptane
   1 ml. stock buffer

4. Standard palmitate solutions

   0, 0.5, 1.0, 1.5 and 2.0 μ moles/ml. in heptane

5. Matched set of cuvettes with cork stoppers and a set of screw capped test tubes - 19 x 150 mm.

6. Spectronic "20" colourimeter (Bausch and Lomb).

7. Vortex mixer.

8. N_2 gas.

Procedure

1. Place 0.5 ml. of plasma, heptane (blank), or standard in a screw-capped test tube and add 5 ml. of extraction mixture. Stopper the test tube and mix for 10 seconds with a Vortex mixer.

2. Add 3.5 ml. of heptane and 2.0 ml. of distilled water. Stopper the test tube and mix for 10 seconds with a Vortex mixer.

3. After allowing at least 30 minutes for the phases to separate, pipette 3 ml. of the upper phase into a cuvette. Do not disturb the contents of the test tube until pipetting is complete or draw any of the acidic lower phase into the pipette.

4. Bubble N_2 gas, which was previously passed through a flask containing heptane, through the solution for 10 seconds and add 4.5 ml. of colour reagent while continuing to bubble N_2 through the solution for a further 10 seconds. Immediately stopper the cuvette.

5. The sample has developed its colour within 1 minute. The colour is stable for at least 12 hours. Read all cuvettes at 560 mμ on the colourimeter.

6. To obtain better readings, expand the scale by setting the blank at 0.70 absorbance and the 2.0 μmole standard at 0.15 absorbance.

APPENDIX TABLE 1

Analysis of variance F values for straw-based diets in three physical forms being fed at three protein levels

Variable	Physical form (F)	Protein level (L)	F x L
Daily feed intake (kg)	4.04^{o}	1.18	2.49
Daily feed intake (g/kg weight$^{0.75}$)	5.36*	1.65	2.98^{o}
Daily digestible energy intake	5.54*	0.31	2.17
Daily crude protein intake	2.73	41.97**	2.61
Daily digestible crude protein intake	1.81	275.3**	4.05*
Standard deviation of weekly feed intake	19.26**	1.80	2.68
Initial weight	0.10	0.26	0.03
Weight change	18.13**	14.08**	21.22**
Increase in gastro-intestinal fill at start of test	0.17	0.82	0.49
Decrease in gastro-intestinal fill at end of test	1.82	0.34	1.31
Weight loss to post-calving	1.03	0.21	2.16
Calf birth weight	0.39	0.11	0.42
Initial fat depth	0.10	0.22	1.78
Final fat depth	0.82	1.13	3.14^{o}
Fat depth change	0.89	0.15	1.39
Plasma free fatty acids	1.25	1.05	2.76^{o}
Plasma urea nitrogen	2.76	57.79**	1.11

^{o} indicates ($P < 0.10$), * indicates ($P < 0.05$) and ** indicates ($P < 0.01$).

APPENDIX TABLE 2

Analysis of variance F values for straw-based diets in the ground and chopped forms being fed at three protein levels

Variable	Physical form (F)	Protein level (L)	F x L
Daily feed intake (kg)	0.25	1.32	2.50
Daily feed intake (g/kg weight$^{0.75}$)	1.84	2.06	3.10
Daily digestible energy intake	5.46*	1.75	1.88
Daily crude protein intake	1.05	40.34**	2.03
Daily digestible crude protein intake	0.46	179.3**	1.12
Initial weight	0.20	0.17	0.03
Weight change	4.97^{o}	31.77**	0.30
Increase in gastro-intestinal fill at start of test	0.30	0.30	0.30
Decrease in gastro-intestinal fill at end of test	3.91^{o}	1.64	0.23
Weight loss to post-calving	0.31	1.75	0.28
Calf birth weight	0.08	0.05	0.52
Initial fat depth	0.09	0.04	2.85
Final fat depth	1.04	0.36	5.94*
Fat depth change	1.66	0.89	1.25
Plasma free fatty acids	2.47	0.88	0.20
Plasma urea nitrogen	2.99	44.86**	2.00

^{o} indicates ($P < 0.10$), * indicates ($P < 0.05$) and ** indicates ($P < 0.01$).

APPENDIX TABLE 3

Analysis of variance F values for intake and digestibility of pelleted, ground and chopped diets

Variable	Treatments
Daily intake	
Dry matter	0.32
Gross energy	0.45
Crude protein	4.87*
Apparent digestibility	
Dry matter	49.3**
Gross energy	11.33**
Cell walls	20.19**
Acid detergent fibre	19.90**
Nitrogen	7.22**

* indicates ($P < 0.05$) and ** indicates ($P < 0.01$).

APPENDIX TABLE 4

Analysis of variance F values for intake and digestibility of low, medium and high protein diets

Variable	Treatments
Daily intake	
Dry matter	0.32
Gross energy	0.27
Crude protein	53.3**
Apparent digestibility	
Dry matter	0.24
Gross energy	0.94
Cell walls	0.02
Acid detergent fibre	0.08
Nitrogen	103.7**

** indicates ($P < 0.01$).

APPENDIX TABLE 5

Analysis of variance F values for two protein sources as supplements to straw-based diets being fed at three protein levels

Variable	Source (S)	Level (L)	S x L
Daily feed intake (kg)	2.11	0.24	0.50
Daily feed intake (g/kg weight$^{0.75}$)	2.75	0.22	0.84
Daily digestible energy intake	1.95	0.60	0.47
Daily crude protein intake	0.60	36.85**	0.59
Initial weight	0.24	0.03	0.03
Weight change	0.71	0.34	0.31
Increase in gastro-intestinal fill at start of test	0.78	0.29	2.63
Decrease in gastro-intestinal fill at end of test	0.11	1.32	0.54
Weight loss to post-calving	0.06	0.39	0.28
Calf birth weight	0.07	0.26	0.25
Initial fat depth	0.01	0.93	0.28
Final fat depth	0.11	2.85	0.13
Fat depth change	0.35	0.57	1.26
Plasma free fatty acids	0.71	0.45	1.29
Plasma urea nitrogen	1.29	52.09**	0.44

** indicates ($P < 0.01$).

APPENDIX TABLE 6

Analysis of variance F values for diets containing three levels of straw

Variable	Straw level
Daily feed intake (kg)	3.03
Daily feed intake (g/kg weight$^{0.75}$)	3.66^{o}
Daily straw intake (kg)	2.15
Daily straw intake (g/kg weight$^{0.75}$)	2.52
Daily digestible energy intake	5.72*
Daily crude protein intake	2.38
Initial weight	0.54
Weight change[1]	3.42^{o}
Weight change[2]	13.81**
Increase in gastro-intestinal fill at start of test	3.40^{o}
Decrease in gastro-intestinal fill at end of test	1.35
Weight change to post-calving	12.42**
Calf birth weight	1.94
Initial fat depth	0.98
Final fat depth	3.72^{o}
Fat depth change	18.66**
Plasma free fatty acids	3.97^{o}
Plasma urea nitrogen	4.47*

^{o} indicates ($P < 0.10$), * indicates ($P < 0.05$) and ** indicates ($P < 0.01$).

APPENDIX TABLE 7

Analysis of variance F values for straw-based diets supplemented with concentrate or hay

Variable	Treatments
Daily feed intake (kg)	9.39*
Daily feed intake (g/kg weight$^{0.75}$)	24.77**
Daily digestible energy intake	7.02*
Daily crude protein intake	9.78*
Initial weight	0.05
Weight change	11.49*
Increase in gastro-intestinal fill at start of test	2.87
Decrease in gastro-intestinal fill at end of test	3.77
Weight loss to post-calving	7.64*
Calf birth weight	2.13
Initial fat depth	1.59
Final fat depth	0.34
Fat depth change	5.93°
Plasma free fatty acids	17.85**
Plasma urea nitrogen	1.33

° indicates ($P < 0.10$), * indicates ($P < 0.05$) and ** indicates ($P < 0.01$).

APPENDIX TABLE 8

Analysis of variance F values for steer diets containing 40, 55 and 70% barley straw

Variable	Treatments
Daily feed intake	4.15^{o}
Daily digestible energy intake	8.67*
Daily crude protein intake	3.18
Daily digestible crude protein intake	2.87
Feed/gain	9.83*
Concentrate/gain	18.71**
Digestible energy/gain	0.76
Initial weight	0.04
Average daily gain	5.10^{o}
Carcass weight	11.68**
Dressing percentage	2.14
Area of rib eye	0.28
Fat cover	6.76*
Marbling	6.14*
Colour	2.33
Grade	4.67^{o}

^{o} indicates ($P < 0.10$), * indicates ($P < 0.05$) and ** indicates ($P < 0.01$).

APPENDIX TABLE 9

Analysis of variance F values for intake and digestibility of 40, 55 and 70% straw diets

Variable	Treatments
Daily intake	
Dry matter	8.02*
Gross energy	6.33*
Crude protein	3.13
Apparent digestibility	
Dry matter	9.65**
Gross energy	9.13**
Cell walls	0.66
Acid detergent fibre	1.42
Nitrogen	0.99

* indicates ($P < 0.05$) and ** indicates ($P < 0.01$).

APPENDIX TABLE 10

Analysis of variance F values for intake and digestibility of weathered and new straw diets

Variable	Treatments
Daily voluntary consumption of straw	5.30*
Daily intake during the collection period	
Dry matter	5.33*
Gross energy	5.33*
Crude protein	12.80**
Apparent digestibility	
Dry matter	40.56**
Gross energy	39.09**
Cell walls	3.92°
Acid detergent fibre	13.89**
Nitrogen	10.78**
Calculated digestibility of straw	
Gross energy	52.52**
Nitrogen	116.3**

° indicates ($P < 0.10$), * indicates ($P < 0.05$) and ** indicates ($P < 0.01$).